"WIRE EDM"

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CERTIFICATE

This is to certify that the thesis entitled, "WIRE EDM" by Mr. Yogesh J. Shah is a record of work carried out under our supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

In the present work, an Electro discharge machine using wire electrode, employing Resistance-Capacitance circuit for spark generation has been designed and developed. The feed movement (2.5 micrometer per step) of the work has been obtained using stepper motor-lead screw arrangement. The constant speed drive for the wire is obtained using capstan rollers, assisted by frictional drive of the take-up spool. In order to have variable wire speed, the main drive is through variable speed motor. The uniform wire winding is obtained by Cam-follower arrangement. Cam has been designed for uniform displacement to achieve uniform winding. Deionized water issued as dielectric medium. It is fed to the machining zone, co-axially to the wire, to achieve efficient flushing. The variation of overcut with voltage and capacitance combination has been investigated using M.S. and tungsten carbide as workpiece material and copper wire (0.23 mm and 0.315 mm) as electrode material using gravity feed flow and forced circulation of dielectric medium. It has been found that overcut increases rapidly with voltage. While it is less sensitive to capacitance. The overcut size observed, is more in case of M.S. than that with tungsten carbide. Forced circulation causes higher overcut than that with gravity flow. The study of other parameters, like surface roughness, surface hardness, visual study of spark eroded surface, and

metallographic examination of the section of spark eroded surface on optical microscope have been carried out. It has been noticed that variation of capacitance doesn't have much effect on surface roughness. The hardness of 'recast layer' is found more than the parent material. Two distinct layers on spark eroded surface have been observed - thin oxide film at the surface and whitish layer below it on M.S. Studies involving material removal rate was not taken up as feed back control arrangement could not be perfected.

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CHAPTER - I

INTRODUCTION

Machining can be broadly described as the removal of excess amount of material to obtain a product of desired shape, size and finish. Machining processes can be classified under (i) Conventional Machining Processes and (ii) Unconventional Machining Processes.

In conventional machining processes, rigid tool with one or more cutting edges is made to interact with the workpiece through a properly controlled relative motion provided between them (feed and depth of cut) causing the removal of the excess amount of material. In conventional machining, the cutting edges of the tool must be always harder than the workpiece so that material is removed only from the workpiece without causing any deformation of the tool.

The rapid development in the field of materials has given an impetus to the modern technology to develop, modify and discover newer technological processes with a view to achieve results that are far beyond the scope of the existing conventional or traditional manufacturing processes. The ever increasing development of High Strength Temperature Resistant (HSTR) alloys has made it more and more difficult to process them by conventional means and even when such machining is possible, it is usually highly inefficient and uneconomical. The need of proper machining of such materials has led to the introduction of special methods of machining. These special methods have

been successful not only in machining these newly developed materials but also in machining parts with extremely complicated configurations. Such processes are commonly termed as "Unconventional or Non-traditional machining Processes".

1.2 Unconventional Machining Processes:

The unconventional machining processes can be classified according to the type of energy used to remove excess material.

(i) Mechanical Processes: Here the material removal takes place by mechanical erosion. Abrasive jet machining uses a focussed stream of fluid with abrasive particles. In ultrasonic machining, material is removed by brittle fracture caused by repetitive impact of small abrasive grains on the workpiece surface at high frequency.

(ii) Electro-chemical Processes: In such processes the metal is removed by ion displacement with some electrolyte as the media. In Electro-chemical machining this is achieved by anodic dissolution of the positively charged workpiece separated from a suitably shaped negatively charged tool by a thin film of flowing electrolyte. In Electro-chemical grinding, metal removal is achieved from conducting positive work piece by rotating a conductive abrasive wheel serving as the cathode with a thin film of flowing electrolyte between them.

(iii) Chemical Processes: The material is removed in these processes by the ablative action under the action of a

chemically reactive agent. Chemical machining is a process of controlled dissolution of material in contact with strong chemical reagent. In chemical etching or milling, material is removed by an etchant solution which is sprayed over the zone of machining or the workpiece is dipped in the solution with the portion not to be machined protected by a suitable coating of etchant resistance material.

(iv) Thermo-Electric Processes: Material removal in these processes is achieved through melting and vaporization. In Electron Beam Machining (EBM) a focussed stream of high velocity electron hits the work surface. The kinetic energy of the moving electrons is converted into heat causing melting and vaporization of the work piece material at the point of impact. In laser beam machining the material is removed by focussed mono-frequency collimated light beam which melts and vaporises the workpiece material at the desired spot. In plasma arc machining a gas like H_2, N_2 etc. is heated by an arc to a high temperature rendering it ionized. This ionized stream of gas impinges on the work surface to cause it to melt and erode. In Electric Discharge machining which is most important, metal is removed from a conductive work piece by a rapid repetitive spark discharge initiated between the negatively charged tool and the positively charged workpiece separated by a flowing dielectric fluid. The above classification shows only the major energy forms used in various types of processes. Actually there is no material removal process which uses only one form of energy. The mechanical energy which is of prime importance in

conventional machining processes, plays a supplementary but important role in other unconventional machining processes.

Of the unconventional machining processes described above, electric discharge machining (commonly known as EDM) is most widely used in production shops as well as in tool rooms.

1.3.1 Electro-Discharge Machining Process:

EDM has been of immense help to the manufacturing and processing industries to produce intricate shapes on any conducting metal and alloys, irrespective of its hardness, brittleness or toughness.

In this unconventional machining process, material removal is obtained by the initiation of rapid and repetitive electrical spark discharges between the tool (or cathode) and the workpiece (or anode) separated by a dielectric fluid with suitable spark gap between them as shown in Figure 1.1. When the voltage gradient set up between the tool and the workpiece is sufficient enough to break down the dielectric medium, a conducting electrical path is developed for spark discharge owing to the ionization of the dielectric fluid. The ionized dielectric, becomes a highly conducting path and allows large current to pass. The fluid becomes again deionized in a very short time after the discharge. The final rate of deionization of the plasma in the spark gap determines the minimum possible pause between successive pulses. If this pause is smaller than the deionization time of the channel, the new discharge will take place at the already established channel due to the

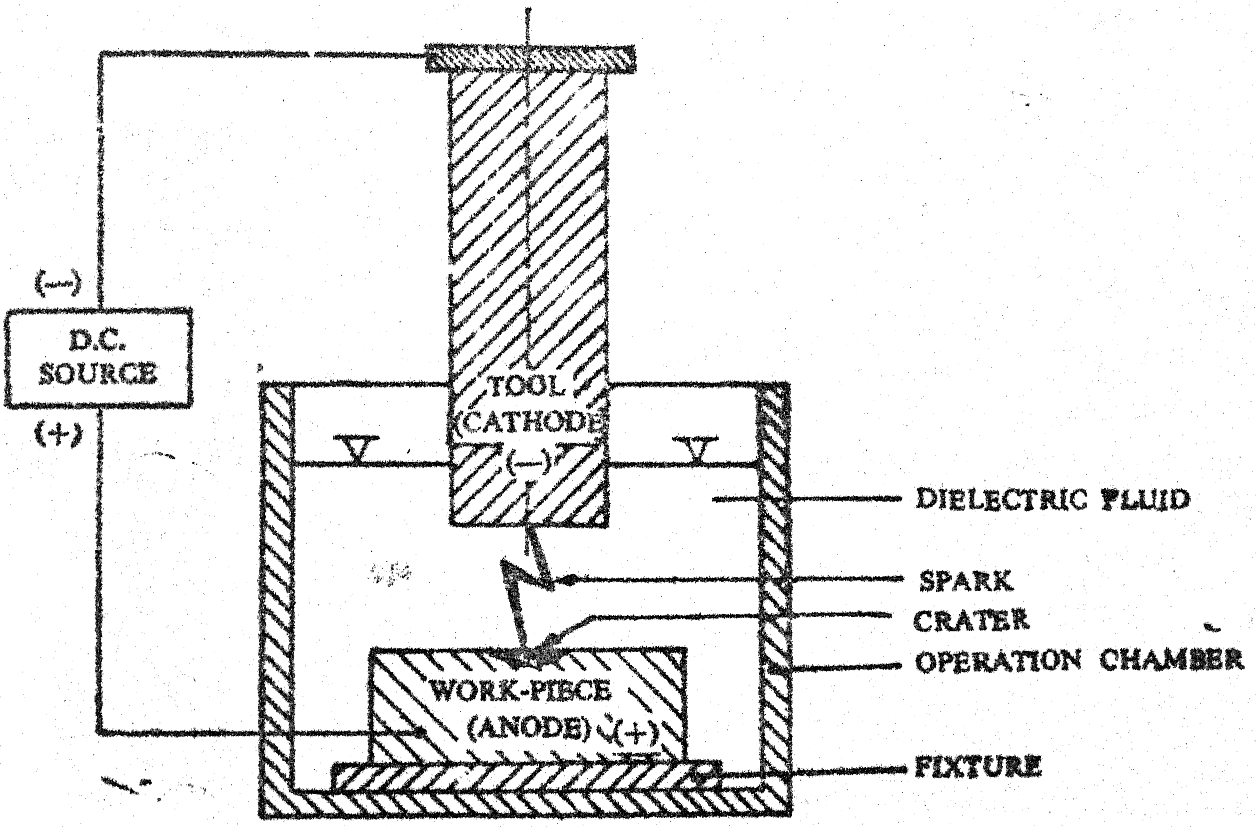


Fig. 5.1 Basic scheme of EDM process

previous pulse with the result that a continuous arc discharge will occur (1).

As soon as a spark takes place, some amount of material will be eroded resulting in the increase of distance from the previous state. The next spark will take place again between such two points where the distance is least, causing further removal of material. Thus the spark will go on shifting from one point to the other and will eventually move all over the tool and corresponding workpiece surface. A part of the metal is removed by direct evaporation and some amount of metal is thrown out of the parent body causing a crater to be formed in the electrode surface. The heat is dissipated in the surrounding dielectric fluid medium and the particles formed are removed along with the dielectric fluid. A controlled erosion of material from the workpiece can be obtained by suitably controlling the various electrical parameters and the gap between the tool and the workpiece. As a result of the material removal from the electrode surfaces the gap between the tool and the work increases. A feed control arrangement moves the tool to maintain a prescribed gap.

Many researchers have put forward the theory of basic mechanism of the spark initiation in the spark gap. Some of them have been described elaborately in the Appendix-I. Out of these theories, the most commonly accepted theory is the collisional ionization of the dielectric medium in the spark gap.

1.3.2 Applications of EDM:

Electro-discharge machining process differs from the conventional processes as follows:

(i) There is no direct contact between the tool and workpiece. Hence there is no force, between the tool and the work.

(ii) The tool need not be harder than the workpiece. The tool electrode is normally made from brass, copper, graphite, copper-graphite, etc.

(iii) Only one electrode can be used to obtain a continuous range of surface finish, from very rough to very fine, simply by changing parameters of the electrical circuits.

(iv) All electrically conducting materials including very tough and brittle ones can be very easily machined.

(v) Since the erosion of the work surface depends on the tool geometry, any type of intricately shaped holes/pockets can be obtained very easily.

(vi) Very fine holes can be easily drilled with great accuracy and ease e.g. fuel injector nozzle for diesel engine.

(vii) Delicate workpieces that are not strong enough to sustain cutting force, can be machined by EDM.

EDM process issued to manufacture both tools and parts of any electrically conducting materials. The major successful applications of EDM include the machining of dies (stamping, extruding, header, wire drawing, forging etc.). A great advantage of the process is that the tools or dies can be spark eroded

after it has been hardened; and hence higher accuracy can be obtained. The process is being successfully used to drill very fine holes in hardened steels, e.g. nozzles for diesel engine fuel injectors. EDM can also produce gears, threads etc. out of hardened blank.

1.4 Electro Discharge Machining Operations:

The various Electro discharge machining operations are listed below:

(i) Electro sprak drilling

(ii) Electro spark grinding

(iii) Electro spark threading

(iv) Electro spark machining of intricate parts by reverse copying method

(v) Electro spark cutting by wire electrode

Reverse copying and drilling by EDM are almost similar. The only difference is in the mutual location of the tool and the workpiece electrodes. The special feature of the reverse copying method is that it makes possible the manufacture of parts of any intricacy without a taper, i.e. with identical cross-section at any point of the length. This is possible only when the tool electrode is below the workpiece. In this case the eroded particles are prevented from getting into machined zone by gases which are formed during the discharge and which carry them away, thus preventing undesirable side discharges. The use of reverse copying method in tool making opens extremely wide ranging possibilities for producing

complete blanking and piercing dies with high degree of accuracy.

In electrospark threading method, an electrode having the shape of a "tap" made from brass, copper or cast iron which is given circular and axial feed. This method can be used in producing threads on carbide tools such as threading rollers, thread gauges, chasers, dies, taps, thread milling cutters etc.

The electro spark grinding of metals differs from the mechanical process in the following points:

(i) During electro spark grinding no force acts between the tool and the part.

(ii) This process does not require any special abrasive materials. The tool electrode is made from ordinary gray cast iron, brass or graphite.

(iii) One electrode can be used to obtain a continuous range of surface finishes, from very rough to very fine, simply by verying the parameters of the electrical circuits.

(iv) Grinding can be combined with case hardening of the surface by alloying it with various chemical elements.

The newest form of electro discharge machining operation - EDM by wire cutting - uses a thin copper, brass, tungsten or molybdenum wire with deionized water as dielectric fluid. Instead of using expensive shaped electrodes, it uses expendable wire to vapourized metal as it moves through the workpiece. Many tool makers report cost reduction in excess of 50% compared to the operational cost of conventional ELM

system (2). The main requirements for machining by wire EDM are that work pieces be electrically conductive and essentially flat, and that all cuts be through through type machining - no blind cavities can be cut. There are no limitations on metals, high strength temperature resistance alloys (HSTR) or even difficult to machine alloys such as waspalloy, Inconel, Alnico and molybdenum-rhenium are readily machined by this process.

1.5 EDM by wire cutting:

Conventional or plunge type EDM has got certain shortcomings which can be easily overcome by EDM by wire cutting without sacrificing the accuracy and the surface finish at economical cost. Shortcomings of plunge type EDM are listed below:

(i) The need to use working electrode with specified tolerances in order to produce the desired shape within the permissible tolerances. So when a part is to be produced with very fine tolerance, the tool should have even finer toleranc which some times is very difficult to achieve.

(ii) The wear of the working electrode inevitably affects the accuracy of machining, one tool electrode can, therefore, produce only a limited number of parts, sometimes only two or three.

(iii) A working electrode can only produce a part of definite shape & dimensions, for another workpiece, regardless of how much it differs from the former, a new tool electrode is required.

(iv) The consumption of labour and material in manufacturing the electrodes is relatively high.

There are mainly two types of EDM by wire cutting machines are available commercially.

(i) Travelling wire-stationary table EDM system

(ii) Stationary wire-travelling table EDM system.

Stationary wire-travelling table EDM is generally used for smaller jobs while for heavy jobs with multicavity travelling wire-stationary table EDM is generally used.

In both of the above systems, the wire electrode is threaded through a starting hole in the workpiece mounted on the table. The starting hole is first drilled before heat-treating (all die blocks are hardened before cutting). The wire is unwounded from the feeding spool by a drive at constant speed, passes through a tension mechanism and through the workpiece. The expended wire is rewound on the take up spool, so that a new electrode is being continuously presented to the machining zone. The dielectric fluid is deionized water, continuously forced fed to the machining zone to flush away the erroded particles from the sparking zone. Water is used, rather than oil or kerosene (as in case of convensional EDM), because it affords better flushing and cooling. This minimizes the "recast surface" effect (2). If ordinary water is used, which is highly conductive due presence of salts, causes incomplete charging of condensers and there is a loss of energy to processes other than machining, such as electrolysis.

Both the workpiece and the wire are eroded in the process, but the erosion of the wire does not affect the accuracy of the cut because the wire passes through the work only once. The size of the kerf is always more than the diameter of the wire used. This is due to the presence of side sparks. The size of the overcut depends on the spark gap and the depth of the crater produced by the single discharge. The schematic diagram of the width of the cut produced by the wire is shown in Figure 1.2. The width of the cut, b, depends on the wire diameter,"d", the spark gap, "l", and the depth of the crater produced by a single discharge, " ".

$$b = d + 2l + 2$$
$$= d + 2o$$

where

$$O = l + \quad = \text{over cut}$$

Also

$$= k\, w_p^{1/3}$$

where

$$w_p = \text{pulse energy} = \frac{1}{2} CV^2$$

$$\therefore \quad O = K\,(1/2\, CV^2)^{1/3} + l$$

$$\therefore \quad O = K' C^{1/3} V^{2/3} + l \qquad (1.1)$$

1.5.2 Wire material:

Copper and brass are normally preferred as electrode material for wire spark-erosion. Both materials have their

own mechanical and electrical properties. Copper is more ductile than brass, it is easier to keep copper wire straight when tension is applied, which is necessary to obtain high machining accuracy. But erosion resistance of the brass wire is high compared with the copper wire. Copper wire in the range of 0.1 - 0.35 mm and brass wire in the range of 0.1 - 0.2mm are generally used commercially for EDM by wire cutting. When sharp corners and high precision is required, tungsten and molybdenum wire in the range of 0.025 - 0.04mm are generally used (3). This is because the resistance to erosion is high in case of tungsten and molybdenum as compared with that of copper and brass. More over tungsten and molybdenum wire have got high tensile strength for the same size of the wire. So high precision of machining and the problem of the frequent wire breakage is least.

1.5.3 Cutting Rate:

Cutting rate of wire EDM is not rapid, compared to most conventional metal-cutting operations, but over all time is comparable to or better than that of many competing processes. One reason is that the tooling - a spool wire is always readily available and requires no special preparation. Because of Computer Numerical Control (CNC) wire EDM system, it can be operated round the clock. This advantage applies, of course only to workpiece involving cutouts that are connected. Parts having number of cavities or cuts require a manual rethreading of the wire electrode for each cutout portion. It has been

found that cutting rates are not linear with workpiece thickness (2), in general the thicker the piece (or stacked pieces upto a maximum height of about 3"), the more efficient the process. For example, hardened tool steel 1", thick is cut at about 1.5 in/hr (in terms of area of cut 1.5 in^2/hr). A 3" thick piece of the same material can be cut at 0.8 in/hr (2.4 in^2/hr) and a 1/8" piece at 7.2 in/hr (only 0.9 in^2/hr).

The reason for the difference is that with a thicker part more electrode area is working at a given time to utilize the available energy. All steels including stainless steel grades, cut at nearly the same rate. In steels, the cutting rate is not affected appreciably by hardness of the material. Aluminium being less dense and having a lower melting point, cuts much faster, carbides cut at only one-half to three-quarters the rate of steel.

1.5.4 Surface finish:

Surface finish of machined cuts is of a matte like texture, in the range of 15-20 micron inches r.m.s. In general, the faster a cut is made (requiring greater power), the rougher the finish. The parts, after machining, are normally cleaned by a simple blassing with fine glass beads. This treatment removes any rust (machining is done in deionized water), particles of resolidified metal that have adhered to the cut surface and traces of copper plating from the wire electrode.

1.5.5 Applications of Wire EDM:

EDM by wire cutting is extensively used in tool and die making industry. All the dies having through through type cavities can be machined by it, e.g. extrusion dies, progressive dies and punches, piercing dies and punches, compound dies etc. Moreover, this process has already been used to make cam-wheels, special gears, stators for stepping motors and similar intricate parts. Wire-EDM is also a companion process to conventional EDM, being used increasingly for fabricating electrodes. It is also used in small-run, high precision production parts (quantities in hundreds). Particularly those made from metals that are difficult to machine by conventional methods. Figure 1.3 shows some parts that can be machined by wire-EDM.

1.6 Objective and Scope of the Present Work:

The major objective of the present work is to design and develop wire EDM at a low cost without sacrificing precision simplicity in design and high material removal rate. Based on these guidelines, it was decided to employ the R-C (relaxation) circuit for spark generation and the stepper motor drive for feeding the workpiece. The other objective is to study a few technological characteristics of the process performance such as the effect of supply voltage and capacitance on the size of the overcut, surface finish of the cut face related to the capacitance, change in the hardness of the cut surface as well as visual study of the microstructure of the

surface produced by the wire EDM on the optical microscope. Apart from these the erosion of the wire electrode will also be attempted. The material selected for these purposes are mild steel and Tungsten carbide.

The major limitation of the machine is, one can't study the material removal rate related to various electrical parameters as it doesn't have feed back control system. The idea of the feed back system was given up because of time limitation and the complexity of the circuits involved. So the study was focussed (as described earlier) on those aspects which are not sensitively dependent on the automatic feed back control system for the spark gap.

CHAPTER II

DESIGN OF THE MACHINE

2.1 Important features of the machine

The design of the whole system has been based on two important considerations-simplicity of construction and low cost of production without sacrificing the essential features listed below:

i) High precision of all moving parts of the machine.

ii) Accurate tool feeding mechanism.

iii) Efficient wire tension mechanism, which can be changed depending on the wire diameter.

iv) Constant speed drive for the wire using capstan rollers assisted by frictional drive of the take up spool.

v) Variable speed motor drive for changing the wire speed depending on the process parameters.

vi) Proper insulation of the path, along which it moves from the structure. So in case of wire breakage, during operation, it will not come in contact with structure untill it has come out of mercury bath.

vii) Efficient and fast removal of the erosion products from the machining zone.

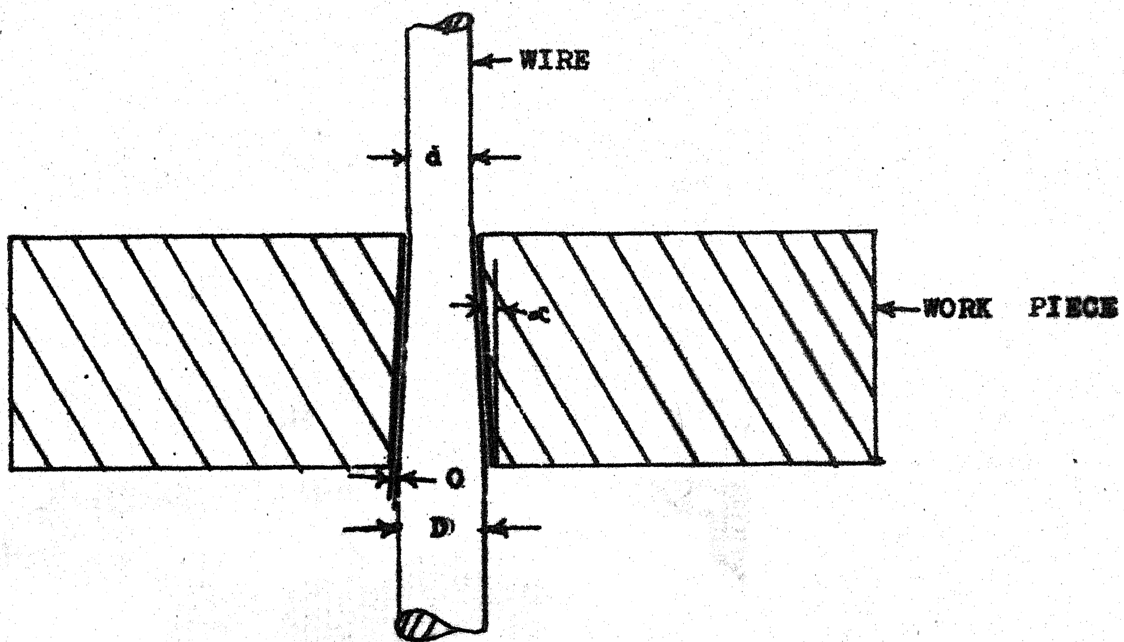
viii) Work feed drive by stepper motor, whose speed can be varied as and when necessary.

ix) Provisions for adjusting the electrical parameters over wide ranges.

2.2.1 Wire Drive Unit

In EDM by wire cutting, it is very important to maintain constant wire speed throughout the machining process once it has been fixed. If the wire speed is lower than the required optimum value for particular set of machining, then there are chances of frequent wire breakage. This is due to the high erosion per unit length of wire at speeds lower than the optimum. This high erosion weakens the wire and the strength of the wire may not be enough to bear the tension set on the wire. More over, the lower wire speed also affects the straightness of the slit (cut) and the high erosion rate of wire reduces the effective wire diameter as it passes through the machining zone. The width of cut decreases, even though the size of the over cut remains constant as shown in Fig.2.1. So, to avoid frequent wire breakage and to maintain the straightness of the cut, the wire speed shouldn't be less than an optimum value depending on the set of machining conditions and parameters.

In the present set up, wire is driven at a constant speed as shown in Fig.2.2, with the help of capstan rollers. The wire is pressed between the capsten rollers which pull up the wire at a constant speed. The idler roller is pressed against the driving roller by the back up plate to ensure positive wire drive is maintained. The main shaft is driven by zero-max. speed motor so that the wire speed can be set at the required value. Generally the wire speed is kept in the range of 0.1 m/min to 8m/min. (4).



D = WIRE DIA. BEFORE MACHINING
d = WIRE DIA. AFTER MACHINING
O = OVERCUT
α = TAPER ANGLE

FIG.2.1, TAPER DUE TO WIRE EROSION

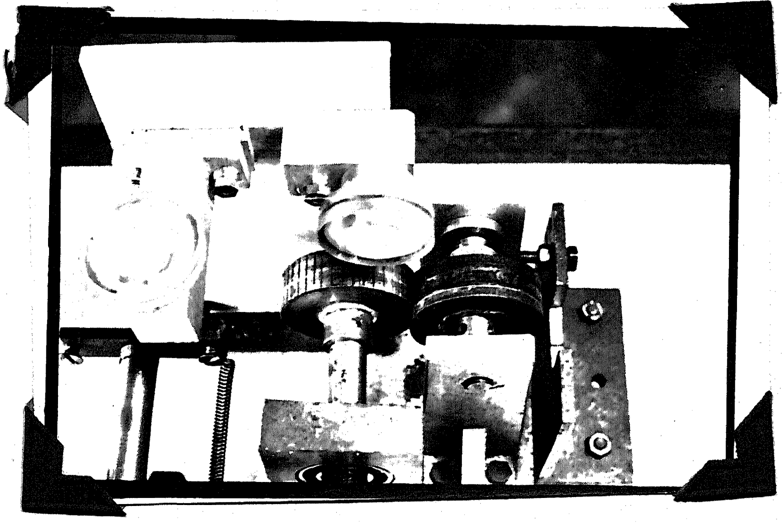


FIG. 2.2, CAPSTAN ROLLER DRIVE

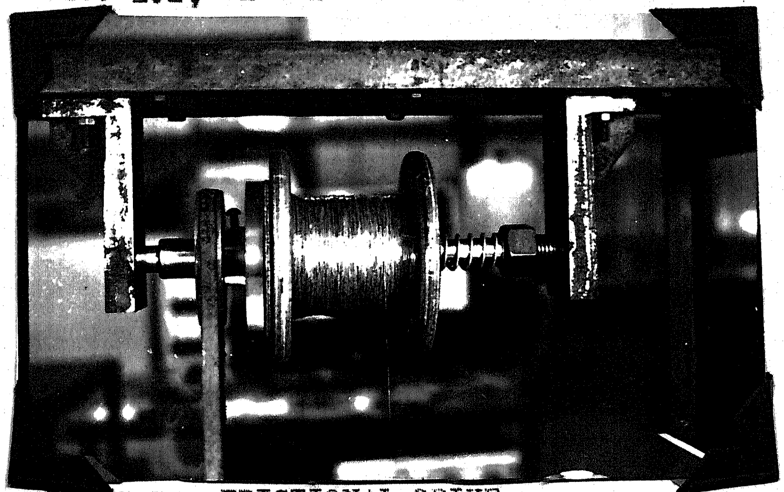


FIG.2.3, FRICTIONAL DRIVE

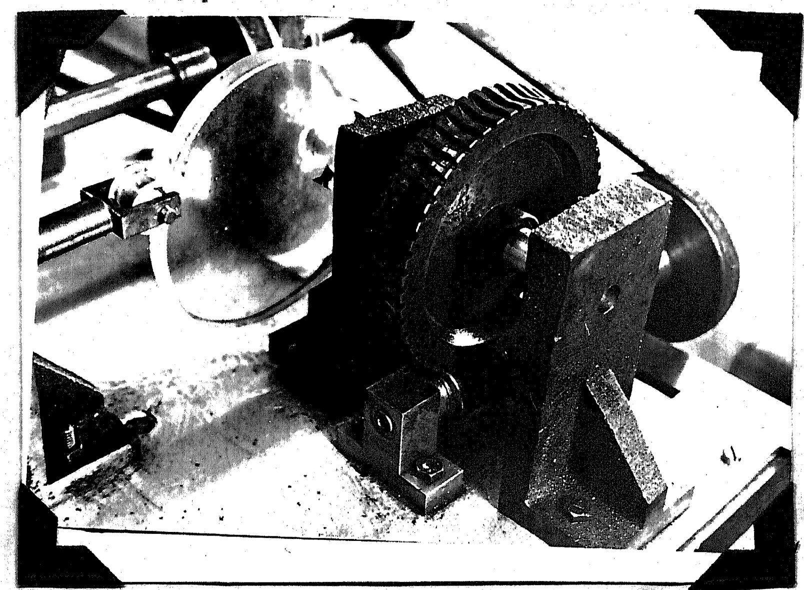


FIG.2.4, UNIFORM WIRE WINDING UNIT

2.2.2 Frictional Drive

After the capstan rollers, the wire is guided to the take up spool through perspex pulleys as shown in Fig.2.3. The take up spool, which receives expended wire, is provided with a frictional drive. The diameter of the spool is kept slightly higher than the capsten rollers and it is driven at the same r.p.m. as capstan rollers. Thus the spool always rotates at a higher speed than the capsten rollers, maintaining enough tension in the wire(beyond capstan rollers) so that wire remains in the guiding pulleys. The spool is freely mounted on the shaft. The spool is pressed against the retaining disc (rigidly mounted) by compression spring. The spring compression has been set in such a way that slight increase in tension in the wire between the region of spool and capstan rollers causes the spool to slip. Thus, it does not affect the wire speed given by the capstan rollers.

The uniform wire winding on the take up spool is obtained by the cam-follower arrangement as shiwn in Fig.2.4. The cam is mounted on the wormwheel shaft. The speed reduction ratio between main shaft and cam shaft is 100:1. In order to have uniform wire winding, the cam has been designed for uniform displacement with the following specifications:

Angle of ascent $= 160^\circ$

Angle of dwell $= 20^\circ$

Angle of descent $= 160^\circ$

Angle of dwell $= 20^\circ$

Follower lift $= 7$ cms.

Base circle radius $= 2$ cms.

2.2.3 Wire Tension

It is very important to keep the wire straight as it passes through the machining zone. For this reason efficient wire tension mechanism is a must. Generally wire tension is kept in the range of 300 to 2500 gms. depending on the wire size and the impact pressure of the discharge i.e. pulse energy (4). If wire tension is not enough for the given machining conditions, then, micro short circuit of the wire with the workpiece will occur. If micro short circuit continues for longer time, then it will result in wire breakage. The percentage of micro short circuit increases when the tension is decreased (5). This means that phenomenon of micro short circuiting is closely related with wire vibration caused by flushing fluid and impact pressure of discharge. Another bad effect of the wire vibration is the increase in size of the over cut when it all the other working conditions are fixed.

Fig.2.5 shows the plot of percentage of micro short circuit duration versus over cut in micron (5). It is clear from the plot that every curve of constant wire tension is parallel to each other when the open gap voltage is the same. So, it is considered that the amount of parallel shift represents the amplitude difference.

The tension arrangement employed in the present machine is very simple and is shown in Fig.2.6. The feeding spool is freely mounted on the shaft and pressed against retaining disk, which is fixed on the shaft by the compression spring as shown.

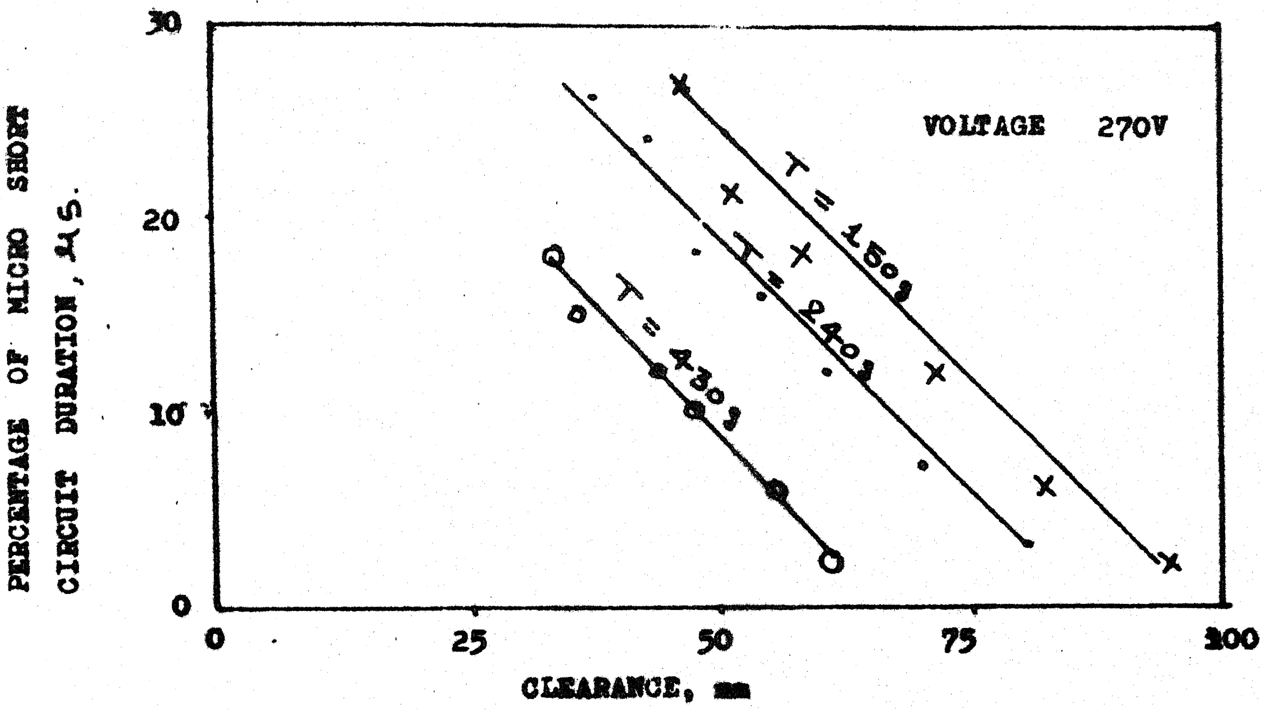


FIG.2.5, PERCANTAGE OF MICRO SHORT CIRCUIT DURATION VS CLEARANCE

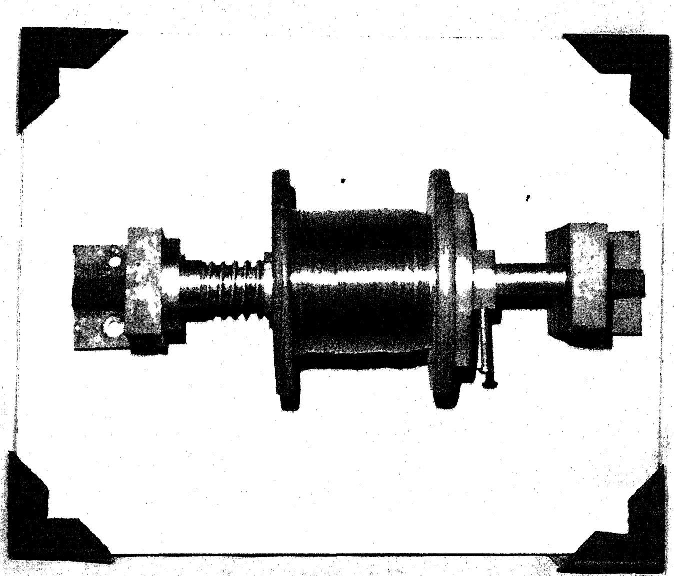


FIG.2.6, WIRE TENSION UNIT

The other end of the spring is mounted coaxially on the stationary sleeve. The position of the retaining disc can be changed to vary the tension in the wire depending on the wire size. The whole assembly, alongwith the shaft is pressed against the flange of the bush bearing, offering some resistance to the shaft motion. The spool is freely mounted, so that the changing of the feeding spool does not give much problem once it has been used up. This tension arrangement is working quite satisfactorily.

2.3 Work Feeding Unit

The workpiece feed unit is the heart of the machine. The least count of the linear movement shall be in the range of 1.25 microm to 2.5 microm, in order to have better control over the workpiece feed back control system. However due to shortage of the time and the complexity of the circuits involved, the idea of feed back control system was given up. This type of feed back control system using stepper motor was employed in plunge type electro discharge machine (6). In commercially available machines, manufactured by Charmille Corporation of U.S.A., also uses stepper motor drive for driving lead screw.

Fig. 2.7 shows the work feed unit assembly. In order t convert the rotational motion to a linear motion, the output shaft of the stepper motor is rigidily coupled to a lead screw, passing through a nut, fixed to the movable part of the slide. The ball type slide has been used. The movable part

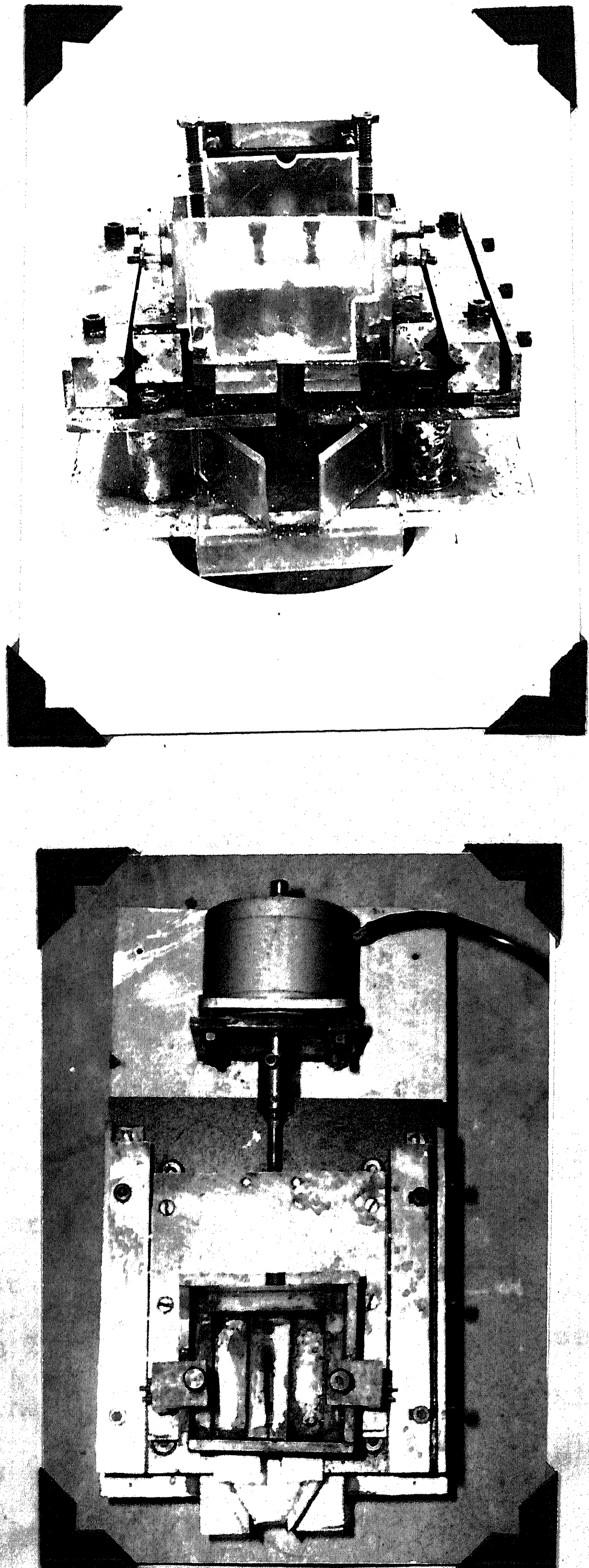


FIG.2.7, WORK FEEDING UNIT

carries a sump, made of perspex for holding and feeding the workpiece in horizontal position. The workpiece is totally insulated from the metallic slide. To obtain the necessary least count of the linear movement, a stepper motor having 200 steps per rotation is selected. Its output shaft, when connected to a lead screw of 0.5 mm pitch gives the least value of linear movement equal to 2.5 microm, per step of the stepper motor, which is quite comparable to the desired one. The lead screw and nut used have no backlash.

2.4 Structure and Accessories

The machine is shown in Fig.2.8. The feeding spool along with the tension unit is kept at the bottom floor. The wire is then guided through the perspex pulleys into the slide at the 2nd floor through a 0.35 mm. perspex sleeve, in order to prevent leakage of dielectric fluid. At the bottom and the top of the slide, wire guides (V-shaped) are kept in order to reduce the free span of the wire across the slide and thereby reducing the possible wire vibrations, for the reason described in article (2.2.3).

Just below the top wire guide, the 'T' shaped glass pipe has been fixed, through which wire passes co-axially, for feeding the deionized water to the sparking zone. The dielectric is fed axially in order to reduce the wire vibration; the flushing is also most efficient when it is fed in this manner. The dielectric is fed through gravity from the perspex tank, kept on the top of the machine. The flow rate is controlled with the help of tap. The deionized water is generall

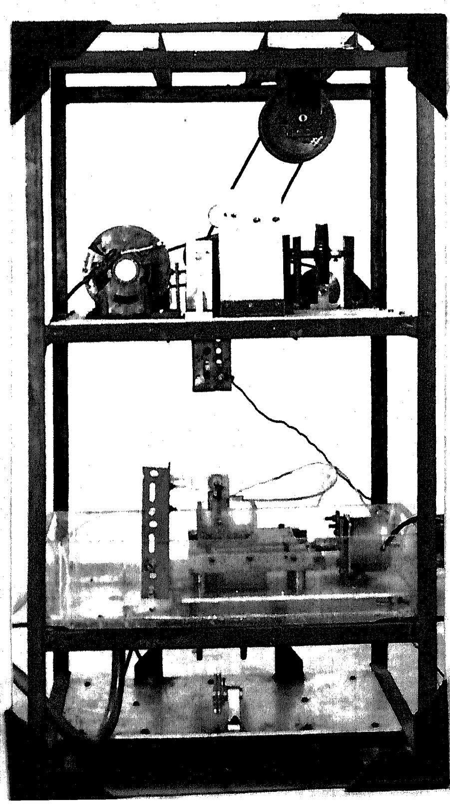
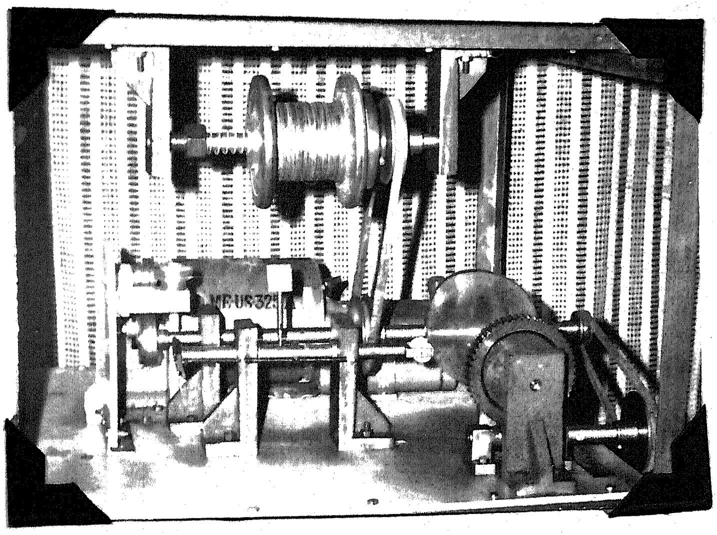


FIG.2.8, WIRE EDM MACHINE

stored in the non-metallic container in order to prevent any possible reaction of deionized water with the metal of the containter. The metallic ions increase the conductivity of the water which results in premature discharge of the capacitance and causes electrolysis of the work piece. Thus loss of the energy in addition to the damaged workpiece surface. The deionized water is obtained by passing distilled water through an-ion and cat-ion exchange resins. The conductivity of the water used was 2 micro-mhos. The used water can be recirculated after passing it through filter, to filter out eroded particles and then through the anaion and cataion exchange resins to remove the dissolve free ions of the eroded metals. In commercially available machines (4) it is generally recirculated as described above.

The negative terminal of the relaxation circuit is connected to the mercury bath, through which wire passes up. The wire, generally passes, from down to up, through the machining zone. This gives efficient cooling of wire by dielectric fluid.



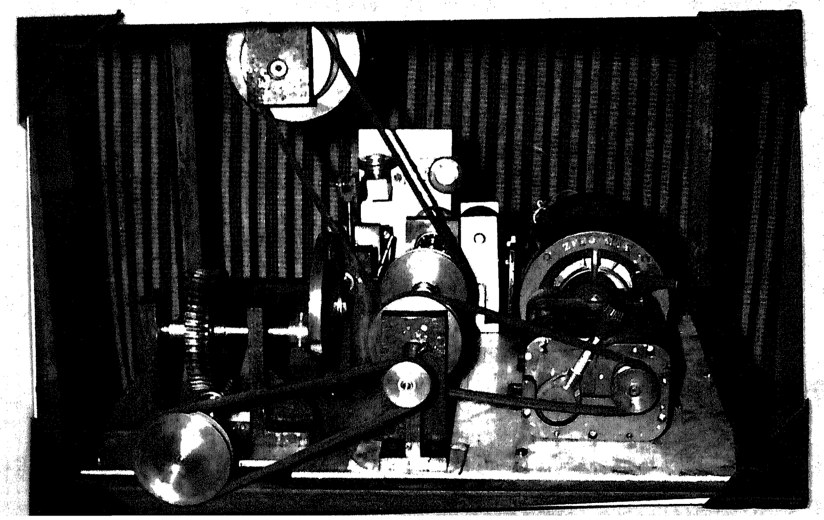


FIG.2.9. DRIVE SYSTEM

On the third floor of the structure the variable speed motor, capstan rollers unit, uniform wire winding mechanism and frictional drive unit are mounted as shown in Fig.2.9.

2.5 Electrical Details

The electrical systems can be divided into two sections:

(i) Spark generating circuit and (ii) Feed control unit.

2.5.1 Spark generating circuit

For supplying electrical energy to the machining gap for generating a succession of uniform electrical sparks, it is necessary to employ a suitable electrical circuit for EDM process. Generally a capacitor is used in almost all spark generating circuits to store electrical charge before discharging operation commences. The maximum metal removal rate is achieved when the capacitor is discharged in as short a time as possible.

In relaxation circuits, an increase in metal removal rate (M.R.R.) depends largely on high amperage and capacitance than on an increase in the sparking frequency (7). It has been observed while machining the workpiece of the same thickness at same voltage but at different capacitance. This causes larger overcuts because of the production of larger chips by the higher energy sparks and thus necessitates greater space for flushing of wear products.

Because of this limitation R-C circuit is best suited for large amount of metal removal where surface finish requirement is not critical. The main advantages of this type of circuit are:

(i) simplicity of construction,

(ii) ruggedness,

(iii) reliability, and

(iv) low cost

Because of non-availability of high power transistors, relaxation circuit was employed in the present set up. The relaxation type spark generating circuit is shown in Fig.2.10. In this circuit, the condenser of capacitance, C, is charged through a charging resistance R_c from a direct current source of potential V_o until the potential of the condenser reaches the breakdown voltage V_c of the gap between the wire electrode and the workpiece. The spark discharge is then initiated causing flow of current which reaches a maximum value shortly after the breakdown of the dielectric as indicated in Fig.2.11. As sparking ceases, the recharging of the capacitor again starts and the entire cycle is repeated.

The premature charging of the capacitor before the deionization of the dielectric layer in the gap is controlled by the charging resistance, R_c, of the relaxation circuit. R_c actually maintains the capacitor charging rate at a desired value avoiding arcing (8). This restricts the maximum frequency obtainable from this circuit to 10-12 KH_z (9). From the

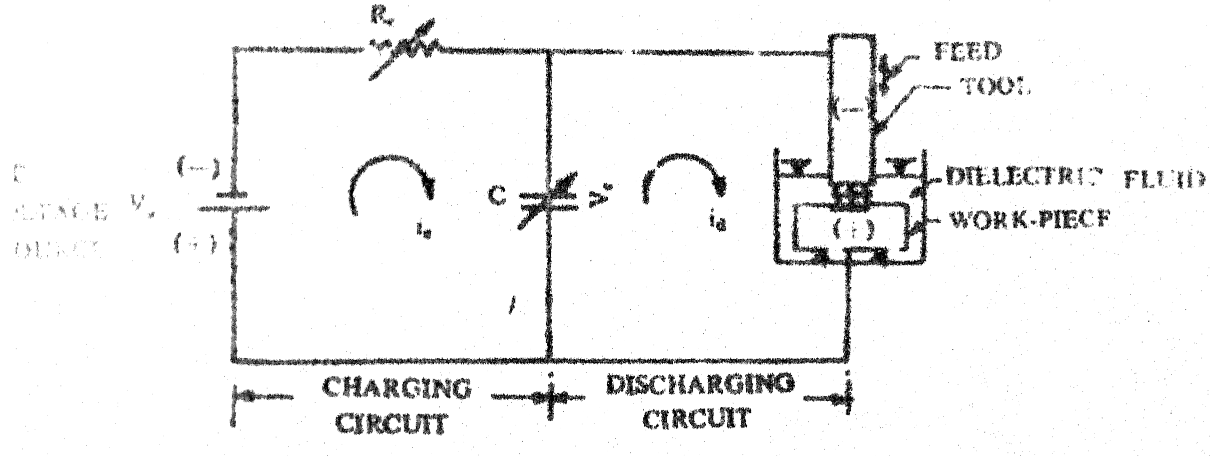


Fig. 2.10 ***Relaxation type of electrical discharge circuit***

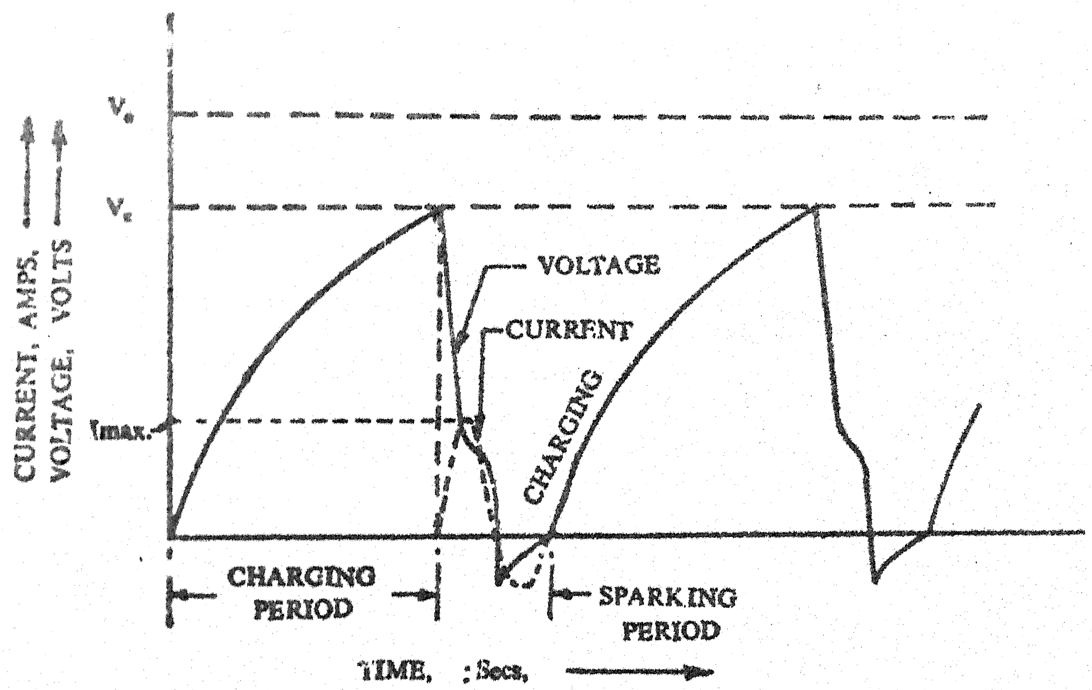


Fig.2.11, Variation of voltage and current with time in relaxation type of circuit

experimental evidence, it is found that

$$R_{c_{min}} \quad 30 \quad L/C$$

where

R_c = charging resistance of the R-C circuit

C = capacitance

L = self inductance of the discharging circuit.

To overcome these inherent difficulties with R-C circuit, many improvements in this circuit (10) and other various types of spark generators (11) have been developed. These generators are also incorporated with different controls to control the frequency, energy, spark duration and pulse shape (12) which in turn affect the production rate, surface finish and accuracy of the process.

When relaxation circuit is employed, material removal rate is given by the equation

$$M.R.R. \quad \frac{V_B^2}{2R_c \ln\left(\frac{V_s}{V_s - V_B}\right)}$$

where

V_B = break down voltage

V_s = supply voltage

R_c = charging resistance.

In order to have maximum material removal rate, power delivery to the discharging circuit should be maximum for the given machining condition. For this break down voltage

should be

$$V_B = 0.71634 \, V_o$$

But due to random fluctuations in the width of the spark gap across which sparking takes place, V_B does not remain constant during the machining process. So it is very difficult to maintain the above mentioned condition for the maximum material removal rate during the actual machining process. Hence, the design has to provide for a prescribed band of voltage which would contain the optimal choice of value of V_B, thus consuming that the process always operates under nearly optimal operating condition.

The schematic diagram of the actual circuit, used for spark generation, is shown in Fig.2.12. The main A.C. power supply goes to a variac through 1:1 transformer used for isolation. The output of variac is then passed through a full wave diode-rectifier bridge to obtain D.C. voltage. This is followed by a capacitance acting as a filter capacitance which smoothens the rectified voltage and a steady D.C. voltage is obtained. The D.C. output then goes to relaxation circuit, constituting variable resistance and capacitance bank. A selector switch chooses four different values of resistance - 20, 30, 50 and 100 ohms respectively. While a selector switch for capacitance chooses six different values of capacitance - 0.3, 0.6, 1, 2, 3, and 4 microfarad respectively. The positive side of this connected to the workpiece where as the negative side is connected to the wire.

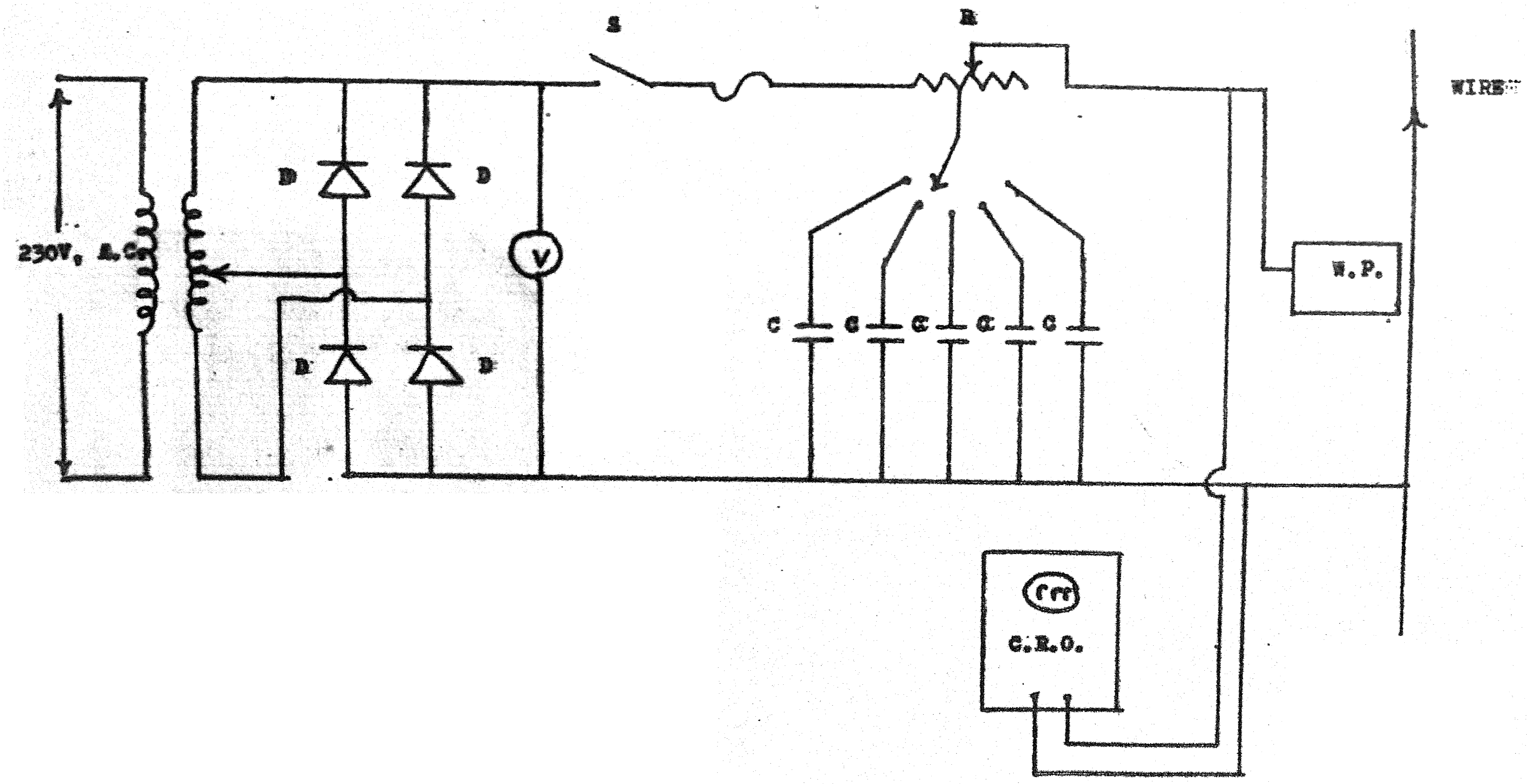


FIG. 2.12. ACTUAL R C CIRCUIT USED

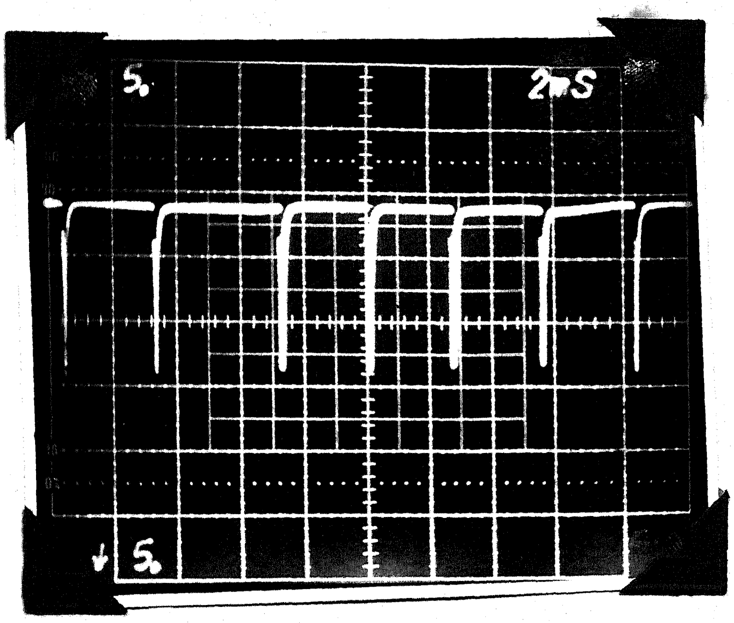


FIG.2.13 SPARKGAP VOLTAGE WAVEFORM

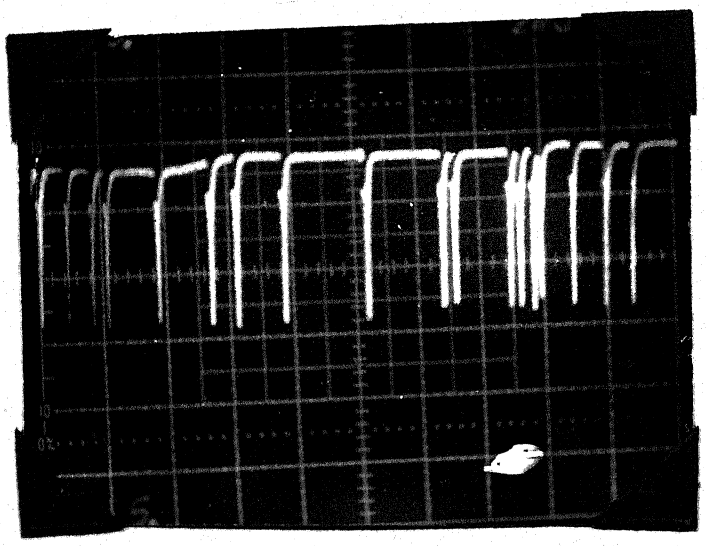


FIG.2.14 SPARKGAP VOLTAGE WAVEFORM

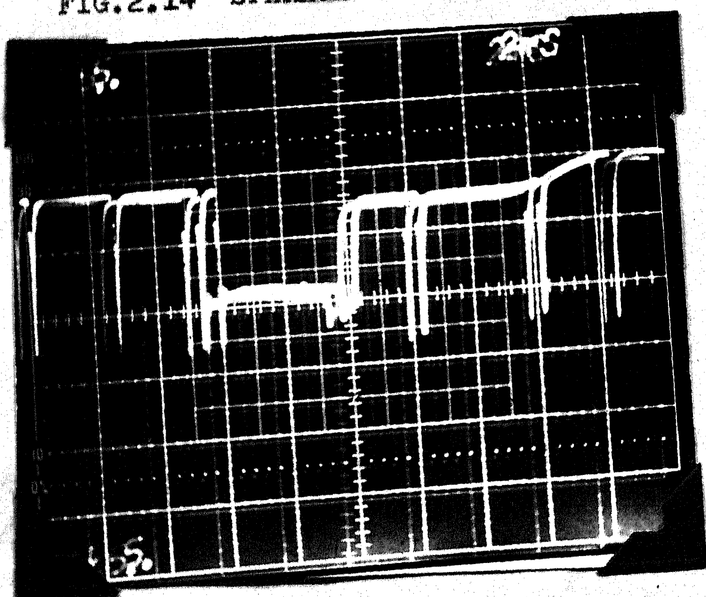


FIG.2.15 SPARKGAP VOLTAGE WAVEFORM

The oscillogram of the waveform of the voltage across the spark gap, which was taken while machining at 100V, 4 microfarad capacitance and 20 ohms charging resistance, is shown in Fig.2.13. It was taken on single sweep storage type oscilloscope when sparking was intermitent. It shows that during intermitent sparking, spark gap voltage waveform remains almost uniform. While Fig.2.14 shows the oscillogram of the spark gap voltage waveform when sparking was continuous. From this it is clear that when continuous sparking occurs, the spark gap voltage waveform does not remain uniform. Also the frequency is higher than that of when sparking is discrete. Fig.2.15 shows the micro-short circuit of the wire with the workpiece. During micro-short circuit, the gap voltage is held at zero level during short period of time. If it continues for longer time, wire breakage will result as described in article 2.3.

2.5.2 Feed Control Unit

In order to have very slow and accurate feed to the workpiece, the lead screw of the ball type slide is rigidly connected to the stepper motor. The stepper motor moves in step and per step movement of the stepper motor, workpiece feed is 2.5 micro-meter. The stepper motor translating circuit, as shown in Fig.2.16 is employed to drive the stepper motor. It consists of sequence generator and power stage. The command signal produced by sequence generator is fed to the power stage. They are then amplified by power stage and fed to the

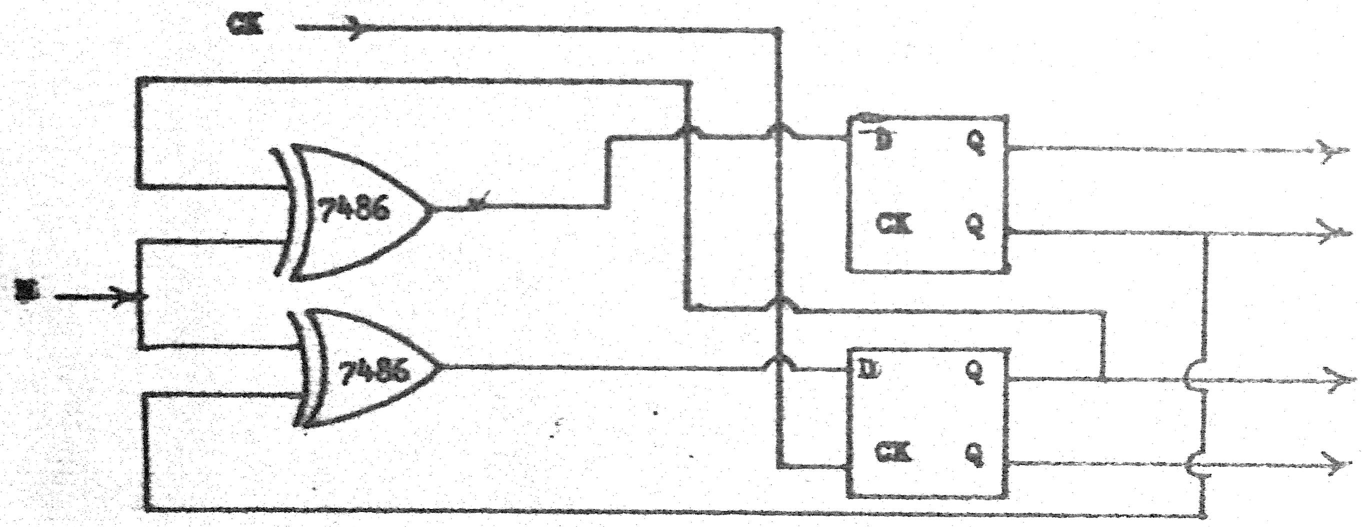


FIG. 2.16a, SEQUENCE GENERATER

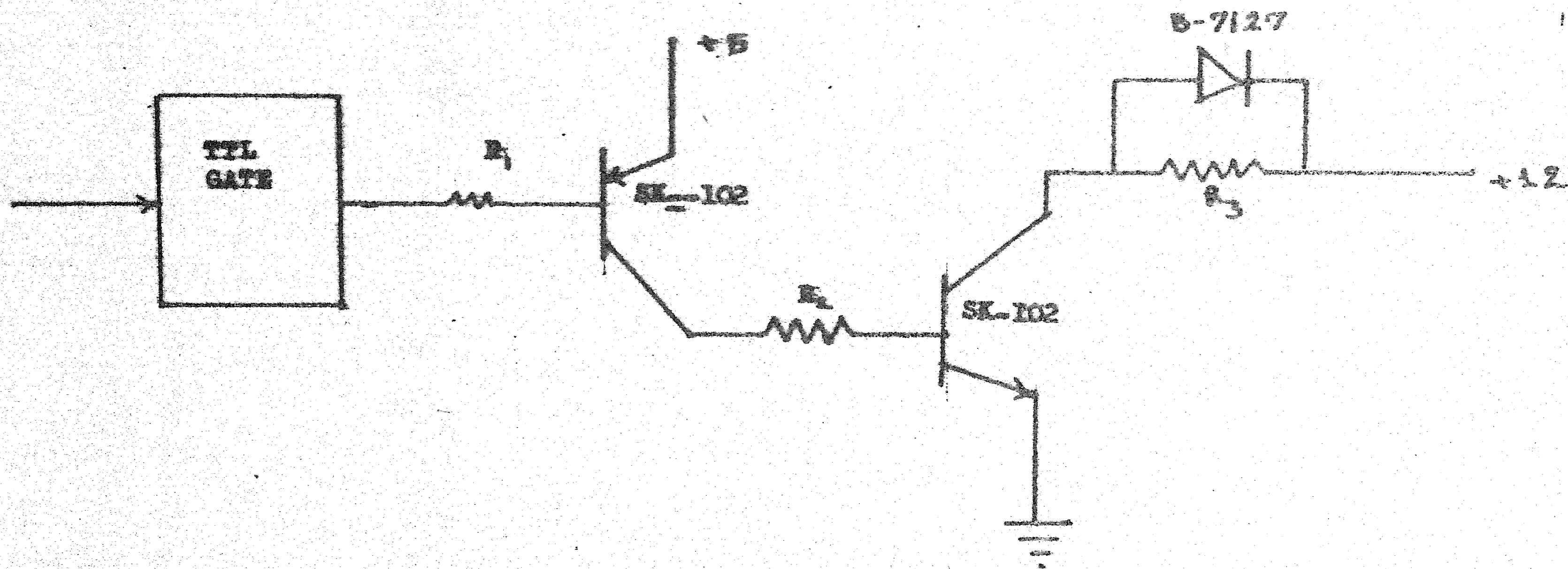


FIG. 2.16b, POWER STAGE

stepper motor. The motion of the stepper motor is controlled with the help of pulse generator. As per set value of frequency, the stepper motor moves that many steps in a single second. So the workpiece can be fed at the required rate. The direction of rotation of the stepper motor can be controlled with the help of toggle switch, which changes the sequence of commands.

CHAPTER III

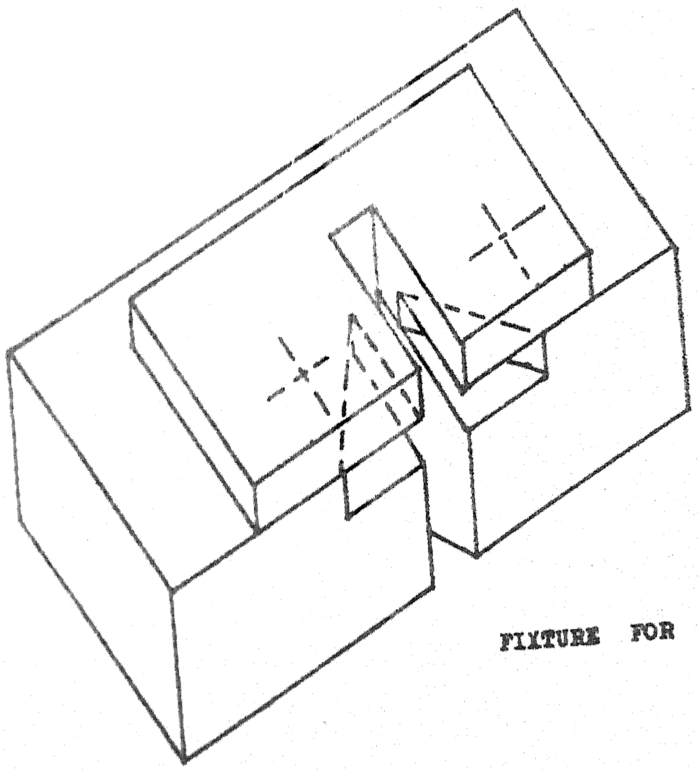
EXPERIMENTAL PROCEDURE , TEST RESULTS & DISCUSSION

In this chapter, the experiments carried out on the machine, have been discussed. The study was concentrated on overcut, surface finish, hardness and visual study of eroded wires and cut surface on the optical microscope. Since the arrangements for feed back control was not ready studies involving material removal rate could not be taken up.

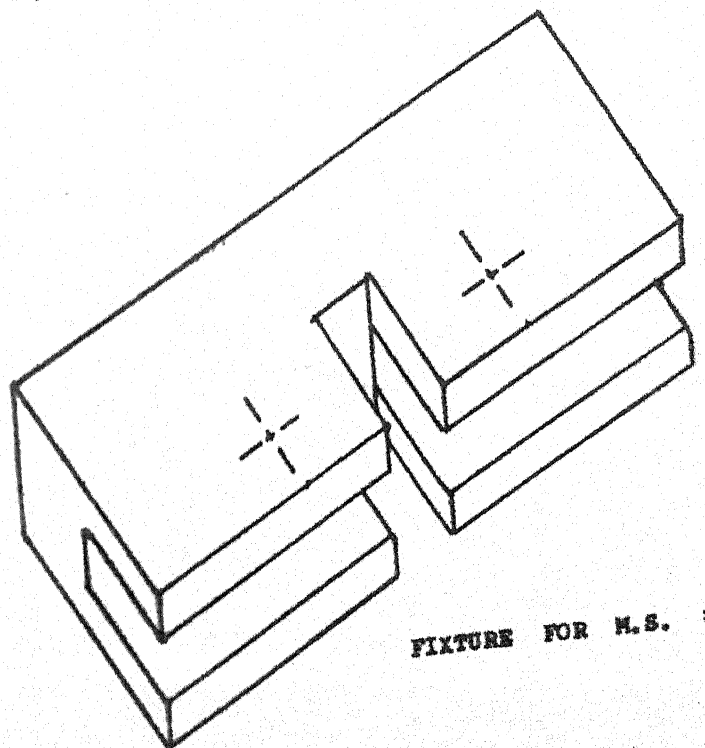
3.1 Effect of Voltage & Capacitance on the Size of Over Cut:

As discussed in article 1.5.1, the size of over cut depends mainly on the spark gap and the depth of the crater produced by a single discharge. The materials selected for studying the various characteristics were mildsteel and Tungsten carbide. The workpieces were cut from hot rolled M.S. sheet of the size 35x10x5 mm. To hold the M.S. workpiece and the triangular carbide tips in position, fixtures, shown in Fig.3.1 were made. Two different sizes of copper wire (0.23 mm and 0.315 mm) and deionized water of 2 micro-mhos conductivity as dielectric medium were used.

The workpiece was clamped on the slide and located for parallelism and perpendicularity. But before that the slide was levelled with the help of **levelling screws.** Then the workpiece was advanced towards the wire with the help of a stepper motor drive. The work surface was held at a distance from the wire to keep the circuit open. The desired value

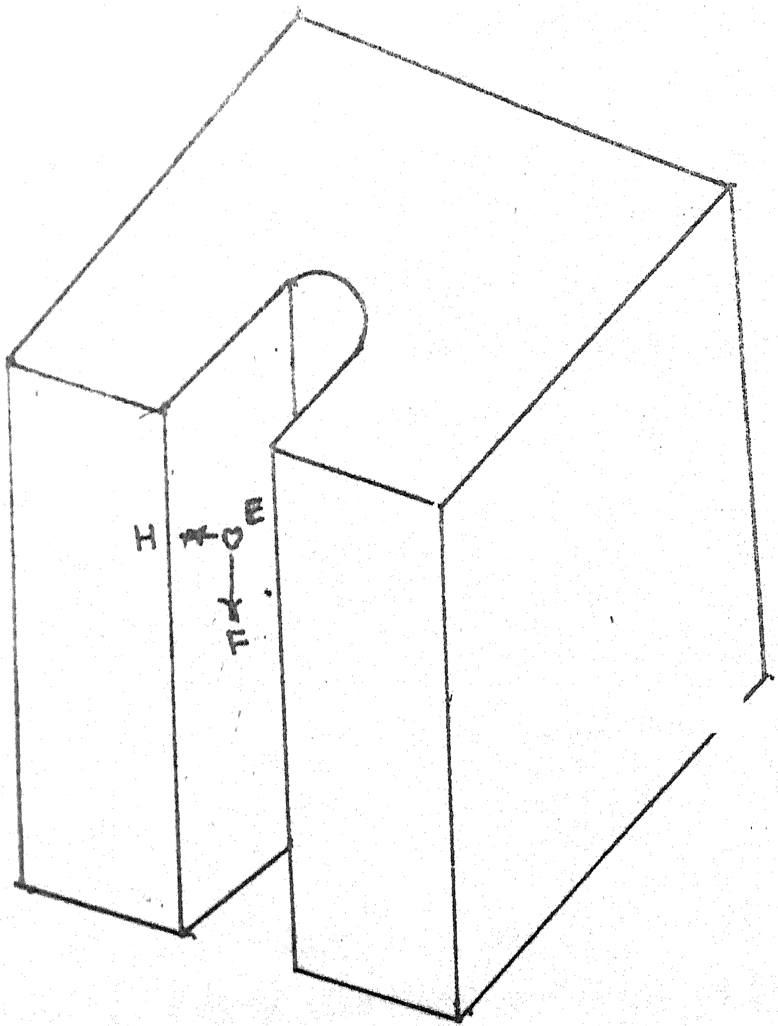


FIXTURE FOR TUNGSTEN CARBIDE TIP



FIXTURE FOR M.S. WORK PIECE

FIG. 3.1, WORK HOLDING FIXTURES



E ERODED PARTICLE
H FORCE DUE TO DISCHARGE
F FLUSHING FORCE

FIG.3.2 FORCES ACTING ON ERODED PARTICLE.

of capacitance from the capacitance bank was selected, while the charging resistance was kept 20 ohms throughout all the operations. The d.c. voltage was adjusted by a variac till the desired value was obtained. Next step was to switch on the wire drive unit and the dielectric flow followed by work feed drive. The machining was started as soon as the required spark gap was reached. The voltage between the workpiece and the wire was fed into an oscilloscope for keeping the check on micro-short circuit of the wire with the workpiece. The machining for each cut was carried out upto 2 to 3 mm length. The study was done for four different values of capacitance -1,2,3 and 4 micro farad. For each value of the capacitance, cuts were taken for five different voltages - 50,75,100, 125 and 150V respectively. Three cuts were taken for each voltage-capcitance combination in order to find out the average values of the over cut.

During experiments, it was observed that machining with high voltages needed high flow rate to flush the eroded particles down the gap. When the dielectric flow rate was not enough for the set voltage, the cut portion was found full of refused eroded copper and parent material particles. The reason for this deposition was insufficient flow rate of the dielectric fluid. There are two forces acting on the eroded particles, (a) impact pressure of discharge in horizontal direction and (b) flushing force in downward direction as shown in Figure 3.2. If flushing force is less than the impact pressure, then eroded particles will not flow down the gap along with

dielectric. These eroded particles which are just in molten state, will get refused on the already cut surface.

Also the problem of the wire breakage was frequent while machining with 0.234 mm wire beyond 125 voltage and 0.305 mm wire beyond 150 voltage. This was because of lowering of the wire strength due to high erosion per unit length of wire at higher voltages. The weakened wire was not capable of withstanding the set value of tension. Another reason might be poor cooling of wire at the machining zone, due to insufficient flow rate.

Figures 3.3 to 3.7 show the variation of overcut with voltage with different values of capacitance for gravity feed of dielectric with 0.23 mm wire. From Figure 3.8 it is clear that for the same value of capacitance, the size of over cut is higher in case of M.S. than that with tungsten carbide for all voltages. This is because of the fact that M.S. has lower melting point them tungsten carbide. So for the same value of pulse energy, the size of the eroded particles will be larger in case of M.S. than tungsten carbide, causing higher side gap (over cut). The eroded particles, thrown out from the frontal gap, also cause extra side sparking, contributing towards the increase in the overcut size. Figure 3.9, however, indicates that there is no appreciable difference in the size of the overcut with different capacitance values. The reason for this small difference in overcut as related to capacitance might be due to the smaller variation in capacitance. From equation (1.1), also it is clear that overcut doesn't depend strongly on capacitance. Figs.3.10 and 11

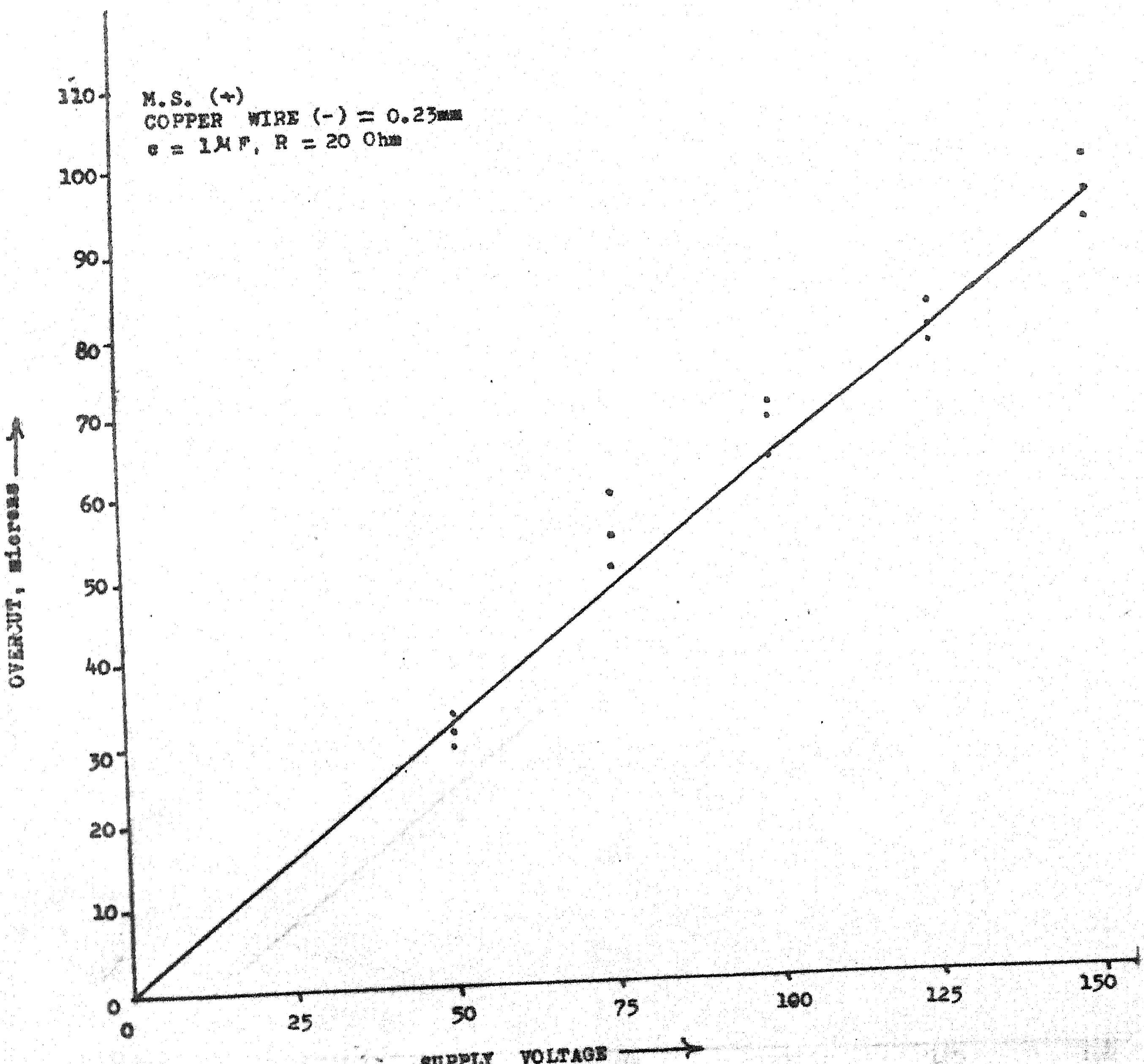


FIG. 3.3 DEPENDENCE OF OVERCUT ON SUPPLY VOLTAGE

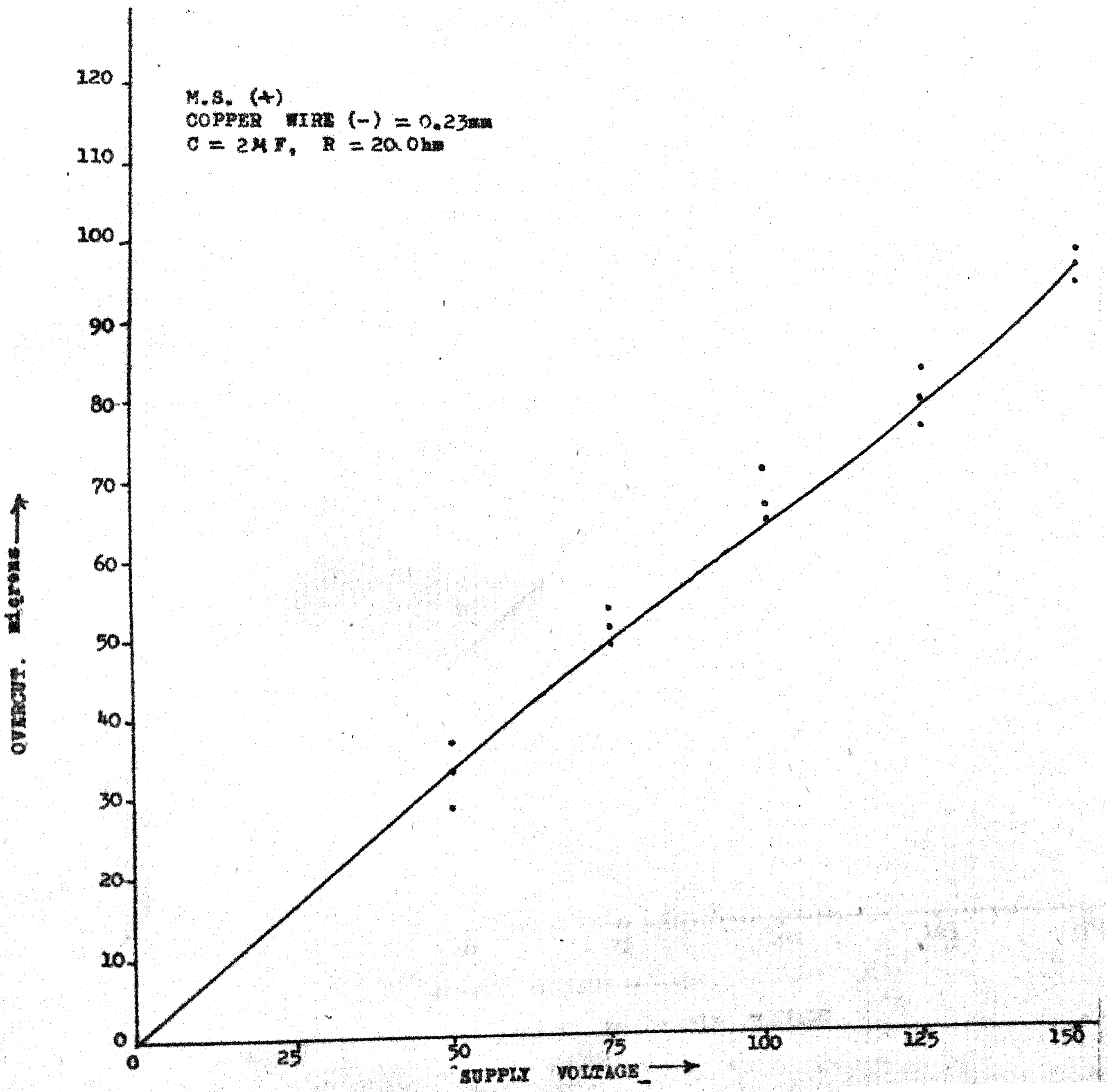


FIG. 3.4 DEPNDENCE OF OVERCUT ON VOLTAGE

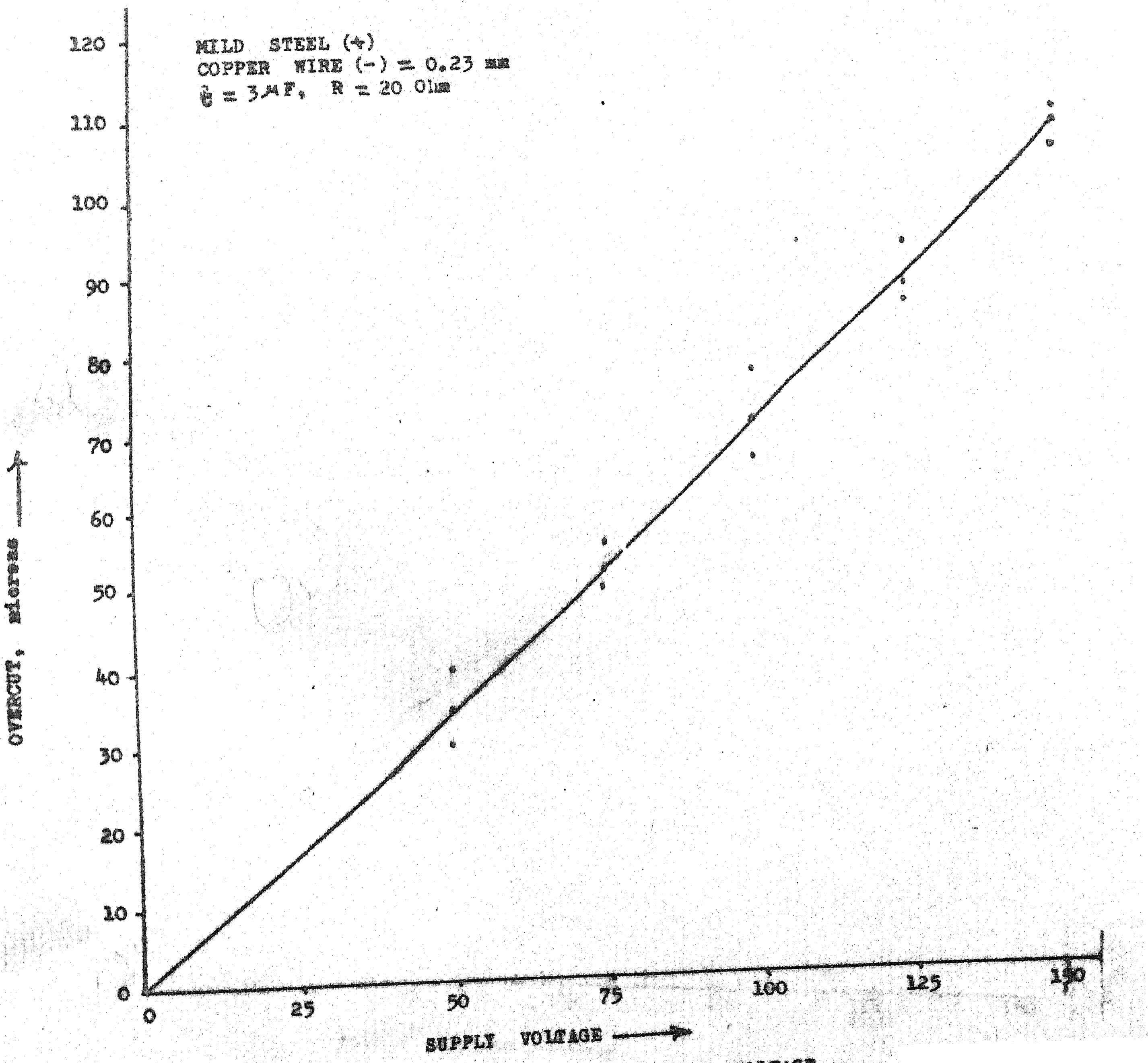


FIG. 3.5 DEPENDENCE OF OVERCUT ON SUPPLY VOLTAGE

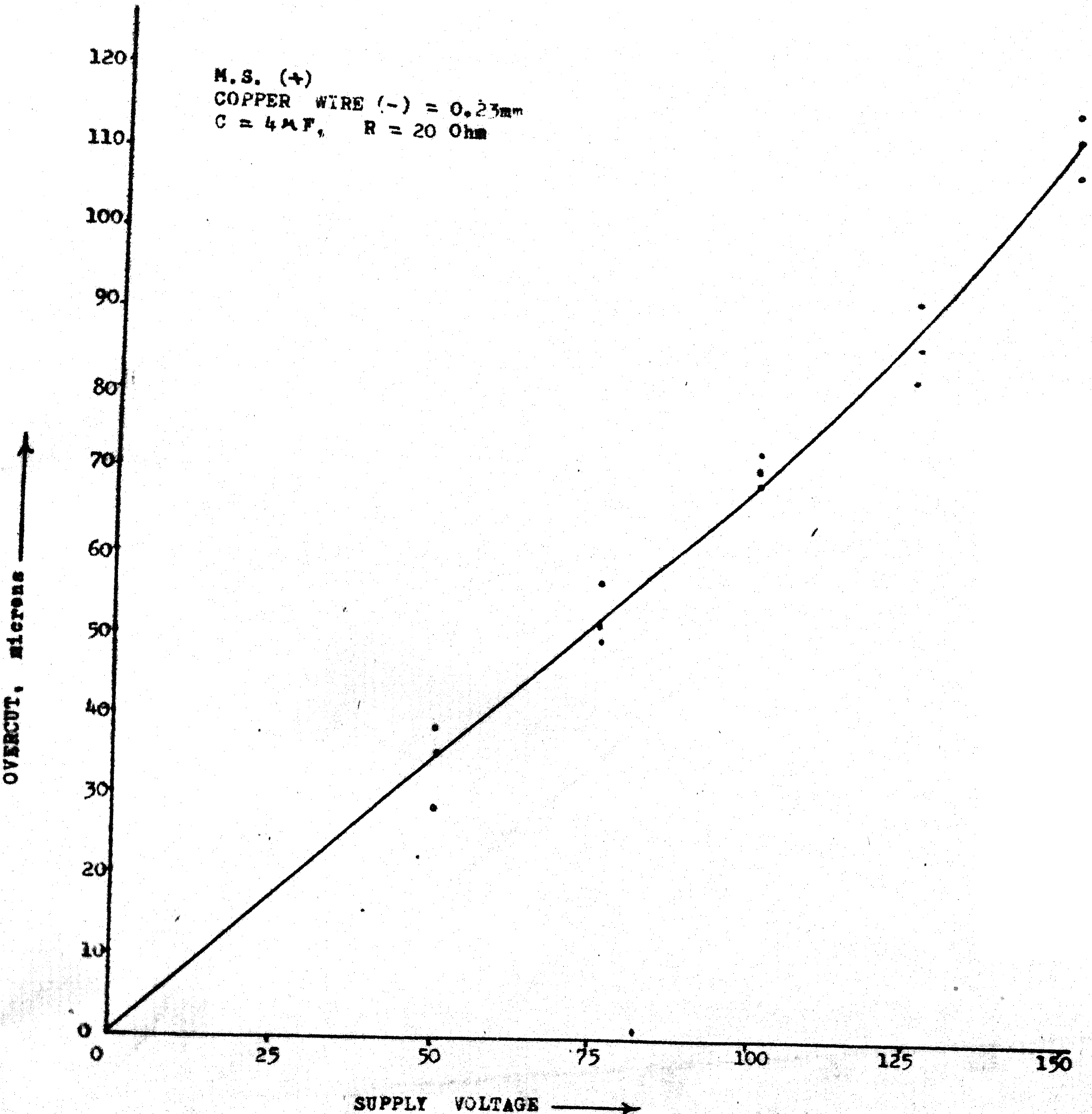


FIG. 3.6 DEPENDENCE OF OVERCUT ON SUPPLY VOLTAGE

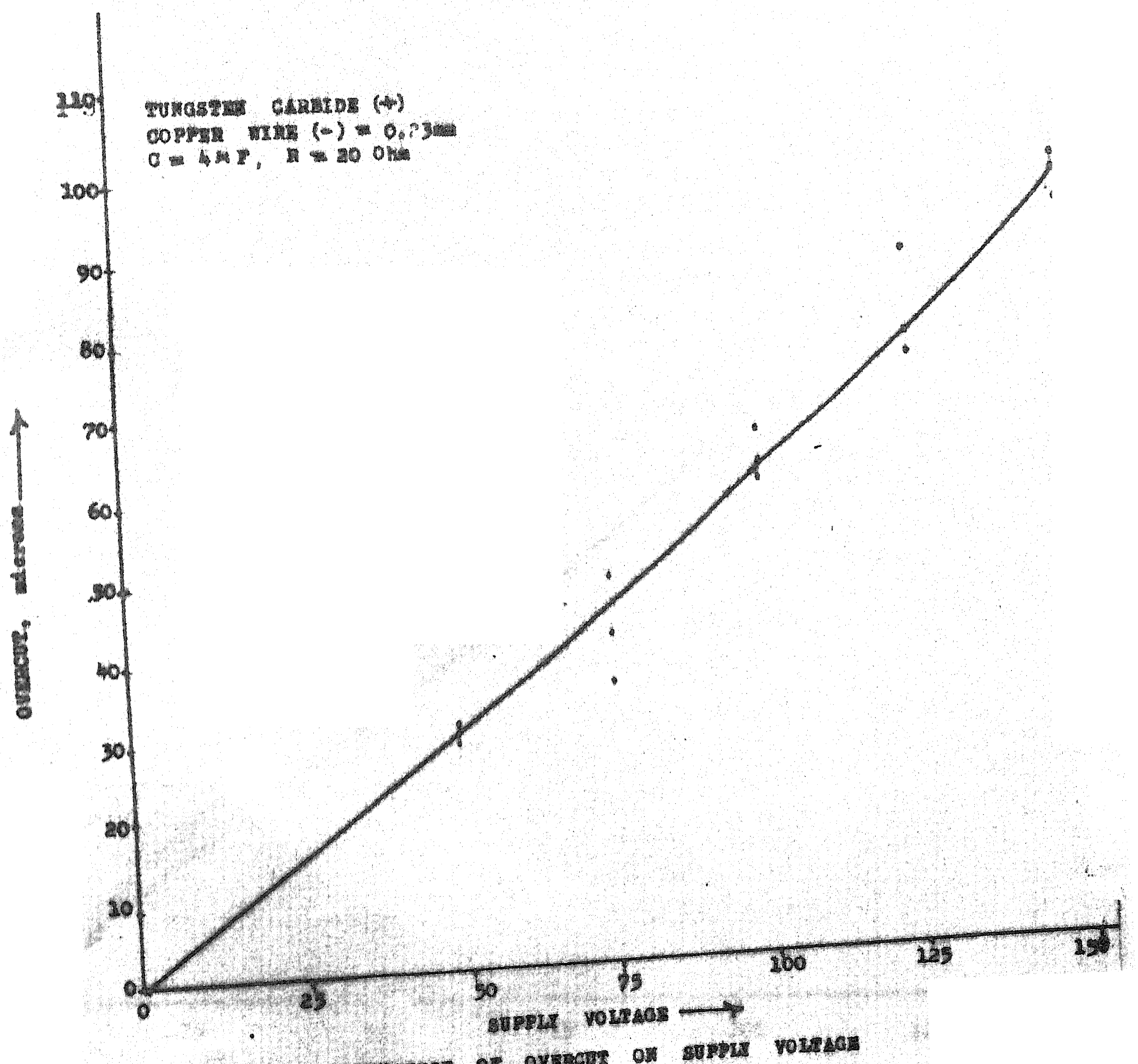


FIG.3.7 DEPENDENCE OF OVERCUT ON SUPPLY VOLTAGE

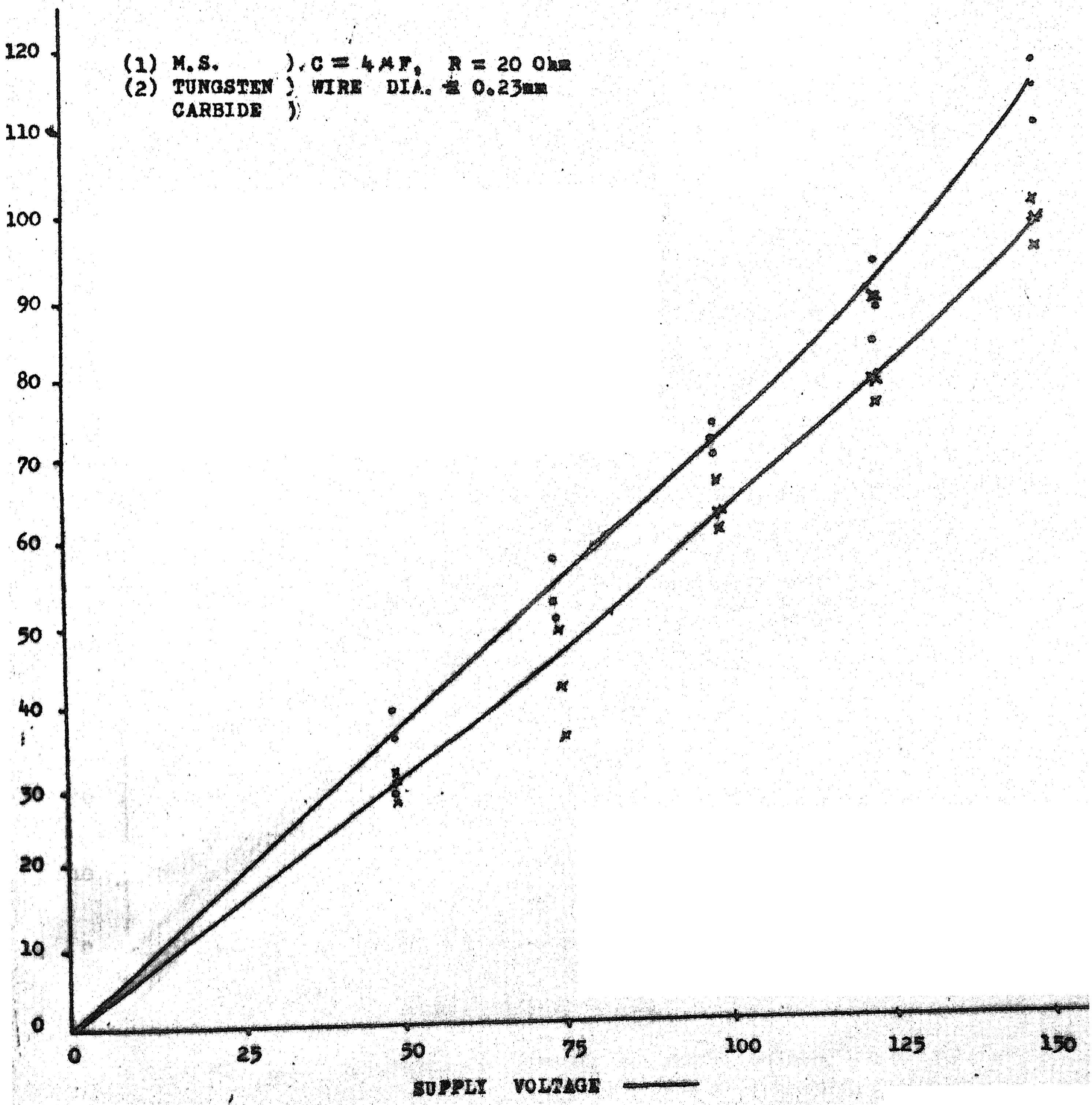


FIG. 3.8, DEPENDENCE OF OVERCUT ON SUPPLY VOLTAGE

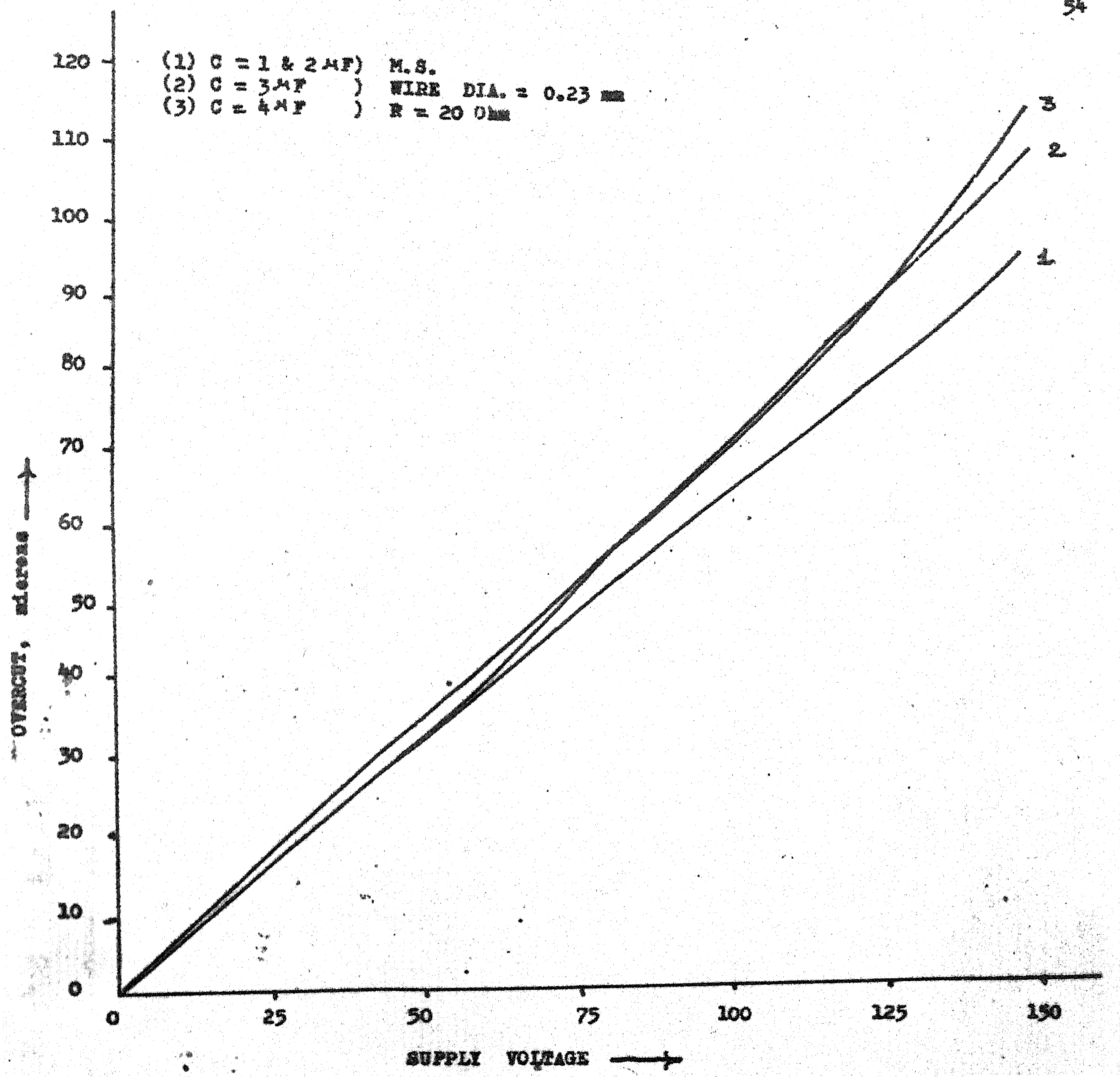


FIG. 3.9. DEPENDENCE OF OVERCUT ON SUPPLY VOLTAGE

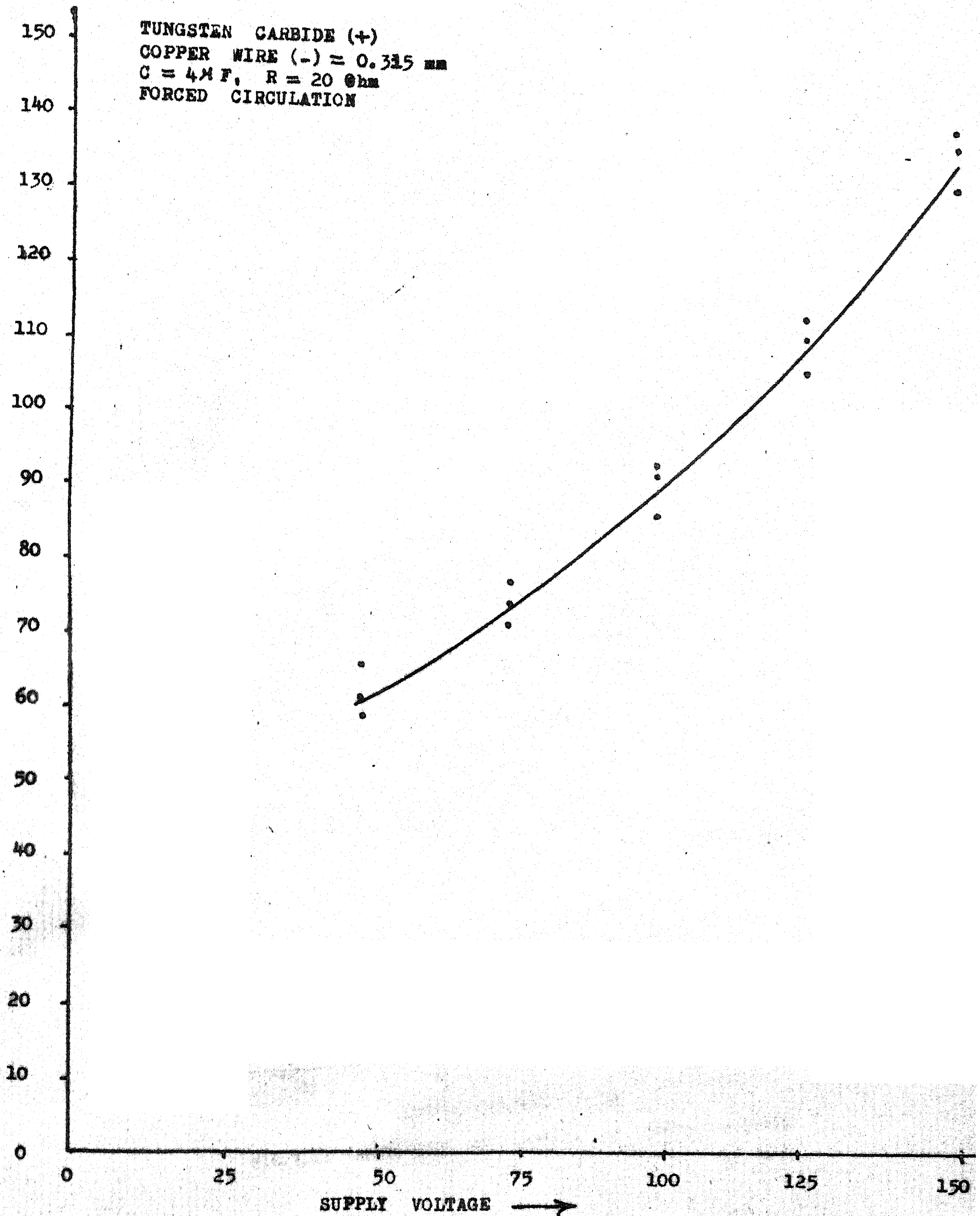


FIG. 3.10 DEPENDENCE OF OVERCUT ON SUPPLY VOLTAGE

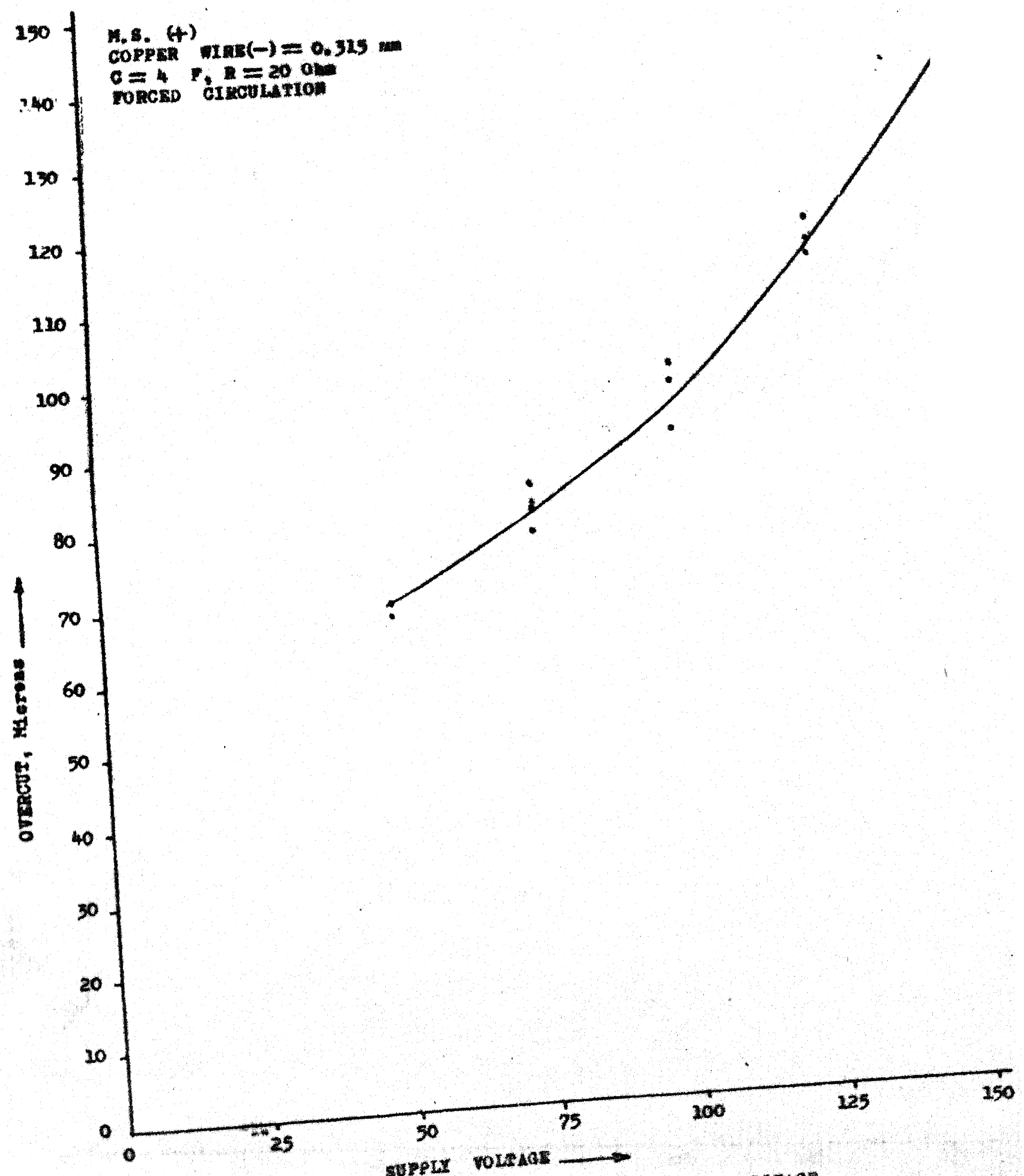


FIG.3.11, DEPENDENCE OF OVERCUT ON SUPPLY VOLTAGE

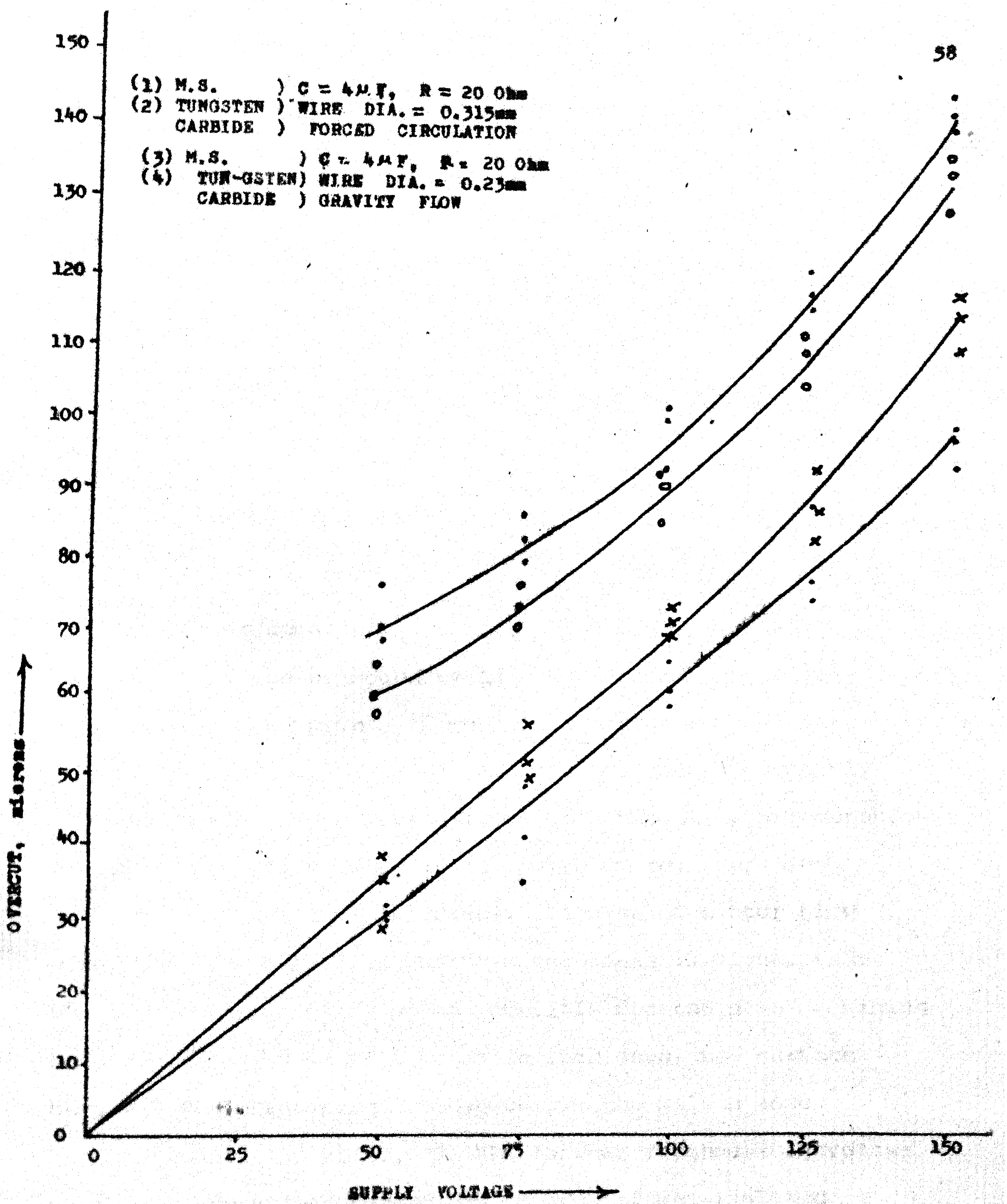


FIG. 3.12: DEPENDENCE OF OVERCUT ON SUPPLY VOLTAGE

show the variation of overcut with voltage for 0.315 mm wire forced circulation. It can be seen that due to forced circulation, the variation of overcut is not linear with the voltage in case of forced circulation. This might be due to excessive vibration of the wire due to forced circulation of the dielectric. This means that either the wire tension was enough to damp down the vibrations caused by forced flow or the flow rate of the dielectric was excessive. Fig.3.12 shows that in case of forced flow the size of overcut is larger than that of gravity flow. The possible reason might be excessive wire vibrations due to forced circulation.

3.2 Surface roughness

Surfaces produced by EDM have characteristically matte appearance and comprises of microscopic craters associated with discrete discharges. In EDM, the surface roughness mainly depends on energy per pulse, types of material, pulse duration and dielectric flushing. As the pulse energy increases, surface roughness also increases. In case of softer (low melting point) materials, surface roughness is higher than the harder (high melting point) materials for the same machining conditions. As the pulse duration increases, the surface temperature increases and consequently the molten zone becomes deeper and wider. So the surface roughness increases with pulse duration, regardless of type of material and polarity (13). It has been reported (14) that an eight fold reduction in machining rate is necessary to reduce surface

roughness to one-half. The scatter in surface roughness from point to point can be ascribed to local variations in discharge conditions. The use of dielectric flushing yields more uniform surface finish (15).

Theoretically, a relationship between the roughness value and crater depth has been derived (16). The average maximum height H_{max} of irregularities obtained by the action of a series of pulses can be approximately found from the following relation:

$$H_{max} = c/3$$

but

$$c = k_1 W_p^{1/3}$$

$$\therefore \quad H_{max} = k_{1/3} W_p^{1/3} \qquad (3.1)$$

where

c = depth of the crater

W_p = pulse energy

k_1 = coefficient depending on type of material of electrodes and the dielectric medium.

The mean square deviation $H_{m.s.}$ of the irregularities from the mean line of the profile can be found from the following empirical equation:

$$H_{m.s.} = k_2 W_p^{1/3} \qquad (3.2)$$

In order to find out the surface finish of machined surface by wire EDM, the M.S. work pieces of 5 mm thickness were cut up to 5 mm.

The experiments were done to find out surface roughness as related to capacitance. The idea of finding out relation between surface roughness and voltage was given up because the feed control unit is without feed back system and at low voltage machining is too slow, so it was causing frequent short-circuiting of wire with workpiece, while at high voltage wire breakage problem was frequent. Hence the machining was done at 100 Volts, for four values of capacitance -1,2,3 and 4 micro farad. The surface roughness was then measured with the Profillo-meter, which gives the average value of the surface roughness. It was found that for all the capacitance values, the surface roughness was in the range of 6.5 micro-m to 9 micro-m in case of m.s. (Fig.3.13) while in case of tungsten carbide it was 5 micro-m to 6.5 micro-m. The surface roughness was higher in case of M.S. than tungsten carbide. This is because melting temperature of M.S. is lower than the tungsten carbide. So for the same value of the pulse energy (i.e. capacitance and voltage), the size of the crater will be larger in case of M.S. than that in tungsten carbide. Also for all the values of the capacitance, surface roughness remained almost same. This may be due to the fact that there is not much appreciable difference in the value of capacitance and also due to the surface roughness measurement was done by Profillo-meter, which gives only average value.

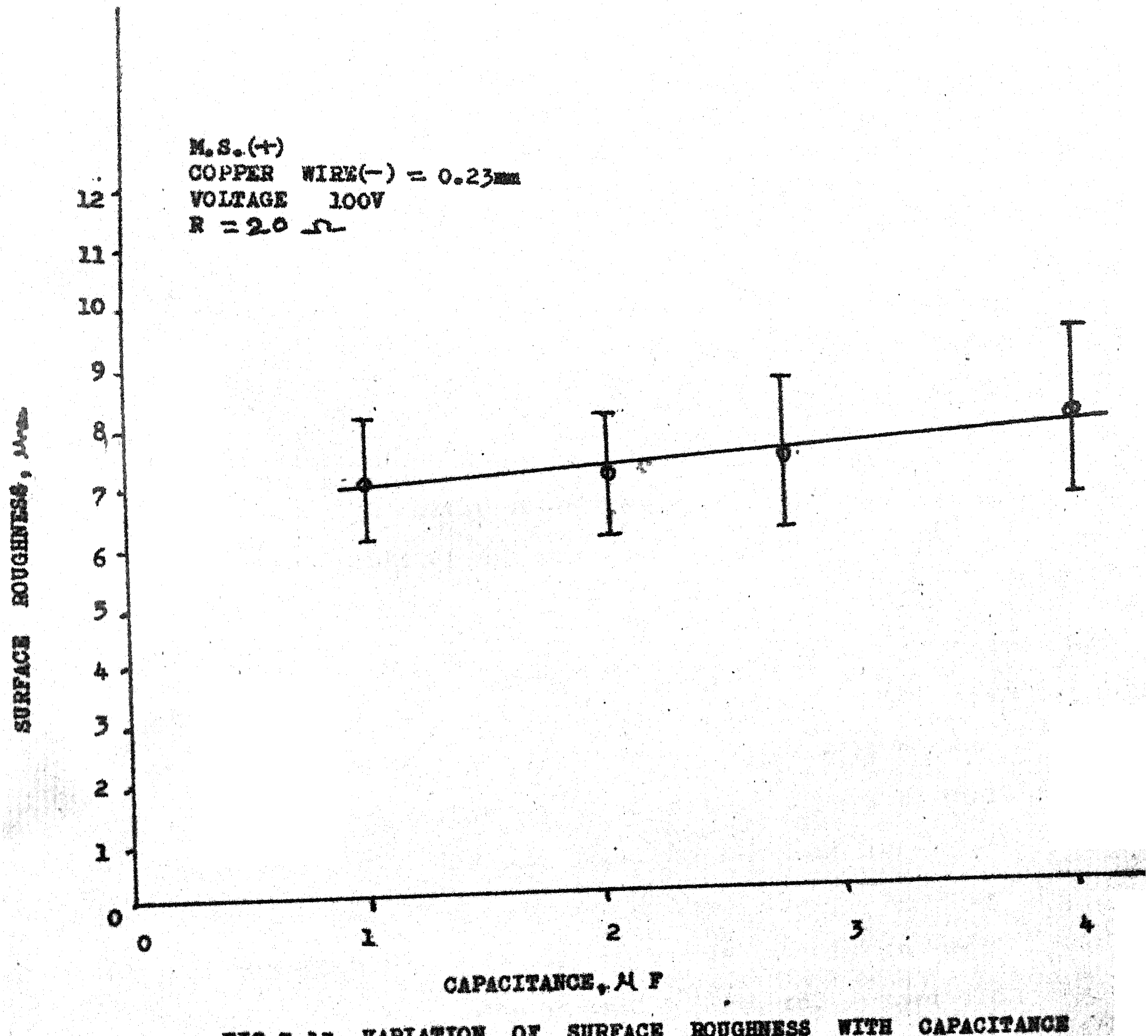


FIG.3.13. VARIATION OF SURFACE ROUGHNESS WITH CAPACITANCE

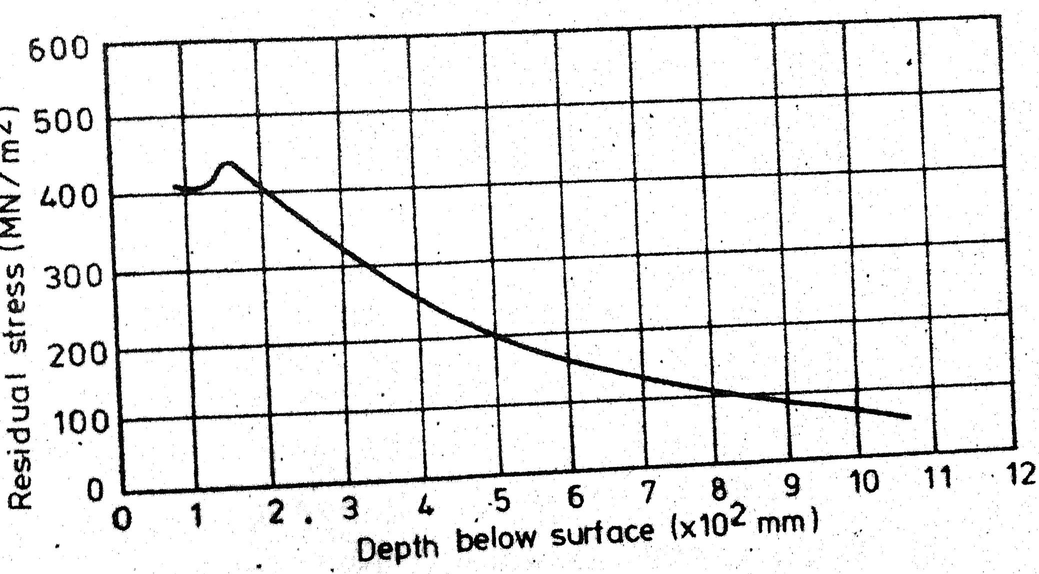
3.3 Surface Properties

The characteristics of the surfaces produced by spark erosion are quite different from those of conventionally machined surfaces. The surface appears as though a pool of molten metal had been ejected from a series of randomly placed and mutually overlapping craters whose edges are apperantly frozen waves of metal. The surface features include overlapping layers, frozen droplets, cracks and pinholes. The melting of metal upon the impact of spark and the violet dispersion of liquid metal with the fall of the discharge pressure and the associated turbulence are thought to be the factors that contribute to the generation of these surface features. The size of pinholes occuring at the surface increases with pulse current and duration (15). The crater sizes have been found mostly to depend upon the material and the spark parameters (17).

Due to the rapid rates of heating and cooling considerable internal stresses (17,18) are developed. The tensile residual stresses were observed to approach the tensile strength of the material at the surface and then fall rapidly to the interior to a relatively low value before giving way to small residual compressive stresses. Residual stresses increases with both pulse duration and pulse energy. Crookal and Khor (19) have investigated residual stress distribution on low carbon steel utilizing pulse and R-C generators. A typical stress distribution pattern is shown in Fig.3.14. Conventional metallo-graphic examinations of section of spark machined surfaces have been employed by many researchers to study

metallurgical changes at the surface. Rudiger and Winkelman (20) reported the presence of a non-etchable white layer, which was far more harder than the parent metal, at the surface. Unusual phase changes in spark machined surfaces can be expected in view of the high temperatures and high thermal gradients established at the surface during machining. The new phases that are formed depends on the dielectric that is used. The usual hydrocarbon dielectrics break down releasing carbon and unsaturated hydrocarbons. This carbon leads to the formation of interstitial solid solutions and carbides. Lloyd and Waren (17) reported the formation of an autenite/carbide surface on pure iron. The use of water as dielectric resulted in the formation of very hard and cleaved surface of almost pure TiO_2 on Ti and mixed oxides on ferrous materials. Williams (21) observed textures on spark machined Tungsten carbide surface resembling those of a fractured surface.

The cracks appearing on micro-sections of the spark machined surface may be categorised as radial, oblique and transversed, depending on the disposition of the crack with respect to the surface. This is illustrated schematically in Fig.3.15. The majority of cracks observed are radial type, i.e. cracks perpendicular to the surface. The oblique and transverse cracks occur at severe discharge conditions. The cracks are seen mostly contained in the recast layer.



b) Pulse energy 0.1 J
Pulse duration 250 μs

FIG. 3.14, RESIDUAL STRESSES IN HW5 TOOL STEEL USING A PULSE GENERATOR MACHINE. TOOL ELECTRODE: BRASS; DIELECTRIC: PARAFFIN.[19]

The spark-machined surface of M.S. was observed on Universal Research microscope (NU-2) at 250 X magnification. The surface appeared as though a pool of molten metal has been ejected from a series of randomly placed and mutually overlapping craters. It was also noticed that frozen droplets of parent material as well as of copper were randomly scattered. At some places the copper deposition was considerable. This might be due to arcing and short circuiting of wire with the workpiece. A few randomly placed pinholes were also observed. For metallographic examination, the M.S. speciman was prepared by cutting across the cross-section of the cut surface and then moulded in bakelite (Fig.3.16) for holding the speciman for subsequent polishing and etching with 5% Nital. Only visual examination was done on NU-2 microscope at 250 X magnification. A very thin black layer was observed and immediately below this, a whitish layer was noticed. This thin black layer may be oxide film due to the formation of iron oxide on the surface as deionized water is used as dielectric. While the white layer is recast layer which could be due to crystallization from liquid phase cooled at high speed. No crack was observed on the section of machined surface. In case of tungsten carbide the machined surface was free from frozen droplets and pinholes. It was similar to fractured surface, comprising of overlapping craters.

Molten and resolidified layer at the surface, "recast layer" is far harder than the parent material. The Vickers hardness distribution across the section of the spark eroded surface is shown in Fig.3.17. It concludes that hardness just on the recast layer is more than that of parent material. It gradually decreases across the depth below the surface

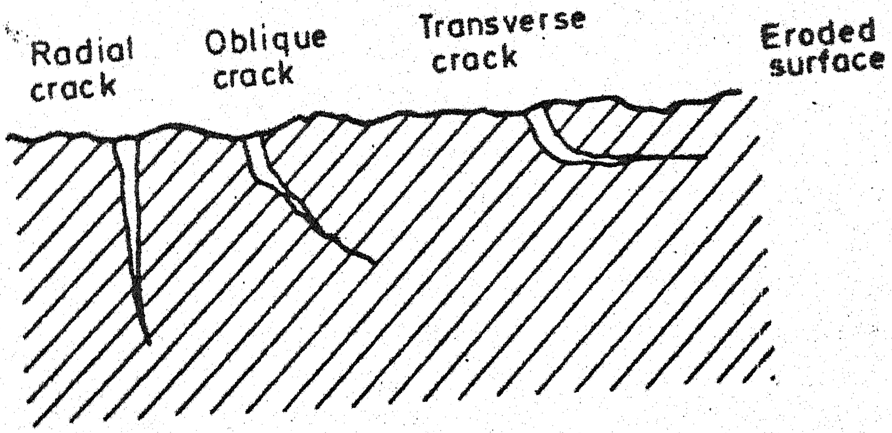


FIG. 3.15. TYPES OF MICROCRACKS IN SPARK MACHINED SURFACES [19]

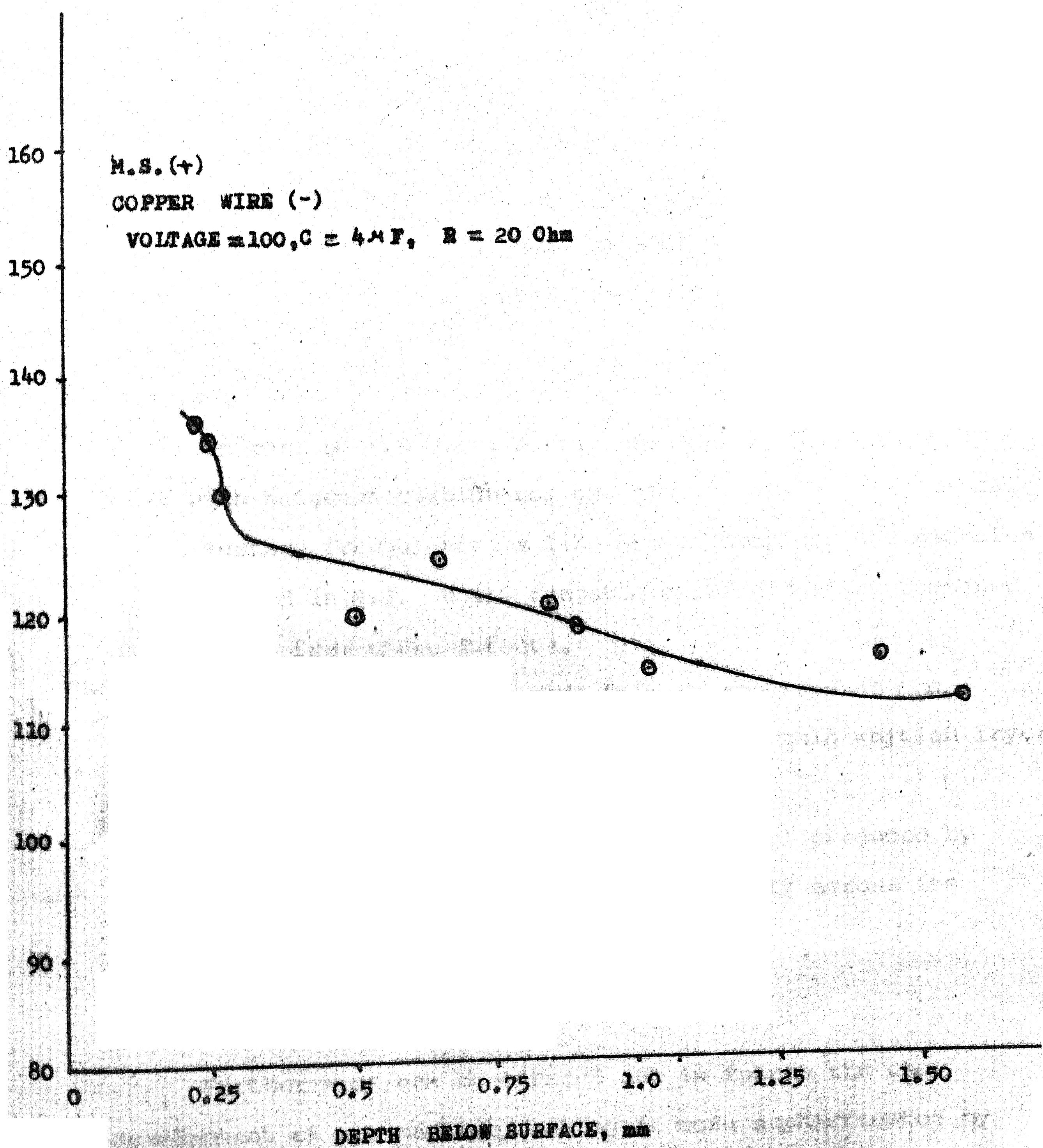


FIG. 3.17. HARDNESS DISTRIBUTION ON THE SECTION OF ERODED SURFACE

CHAPTER IV

CONCLUDING REMARKS & SCOPE OF FUTURE WORK

From the experimental results described in previous chapter, the following conclusion can be drawn

1) In general, the size of overcut increases rapidly with voltage. While it is less sensitive to capacitance.

2) It is observed that the overcut is more in case of M.S. than that with tungsten carbide for all voltages.

3) Forced circulation produces larger overcut than that with gravity flow of dielectric in M.S. as well as tungsten carbide.

4) In case of M.S., the surface roughness is higher than that with tungsten carbide for the same machining conditions.

5) Surface irregularities like frozen droplets and pinholes are observed in M.S. While tungsten carbide surface remained almost free from these defects.

6) A very thin layer of oxide film is observed on the machined surface of M.S. Below this layer a thin whitish layer of recasted parent metal has been noticed.

7) The micro-hardness of the 'recast layer' produced by spark erosion is more. It decreases gradually across its section.

4.2 Scope of Future Work

Further work can be carried out in future for the development of the machine, making it more sophisticated by

employing digital feed back control system. The R-C generator can be replaced by transistorized pulse control generator so that pulse energy and pulse duration can be controlled. The work feeding slide can be improved by making it two dimensional with angular movement. With these improvement extensive experimental work can be done for different wire-job combination for various parameters.

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APPENDIX I

The sequence of events constituting the process of metal removal from the work surface by a single discharge in EDM process, can be explained in the following way.

As soon as a suitable voltage is built up across the tool and the workpiece, the break down of the dielectric medium will take place owing to the development of a strong electrostatic field between the electrodes. As a result, there will be a cold emission of electrons from the micro-irregularities or from the small protrusions on the electrode surfaces having the shortest distance in between. Thus, free electrons, liberated from the cathode surface, will be accelerated towards the anode by the electric field and will acquire high velocity. These high velocity free electrons will collide with the dielectric fluid molecules and thus electrons will be liberated from the molecules. As a result the dielectric molecules will be broken up into electron and positive ion; causing the ionization of the dielectric medium in the spark gap. This will decrease the resistance of the fluid layer and an electrical discharge will be initiated with the resulting flow of electrons.

Each electrical discharge causes a focussed stream of electrons to move with a very high velocity and acceleration from the cathode towards the anode and ultimately creates compression shock waves on both the electrode surfaces. The pressure created by the wave is many times higher than the

ultimate strength of the electrodes. The generation of the compression shock waves develops a local rise in temperature and a certain surface layer deformation. The phenomenon is accomplished within a few microseconds and the temperature of the spot hit by electrons may rise upto thousands of degrees. Actually the mechanism of thermal conductivity has no time to start before the violent process of energy transfer is completed. So the entire energy can only be expended in the surface layers of the electrodes. The inertia of the surrounding dielectric medium develops a high pressure and creates a blast causing the metallic globules, leaving craters in anode and cathode surface.

While Horsten has shown that the break down in liquids would not be introduced by collisional ionization of molecules. The mean free path length in liquid is comparatively small and hence electrons cannot gain sufficient kinetic energy to cause ionization. Electron leaving the cathode by field emission drift through the liquid molecules towards the anode and cause heat to be generated within the fluid. After the ignition delay, the liquid evaporates locally giving rise to gas bubbles. Now break down can occur due to collisional ionization. Following ionization, the resistance of the current path will decrease and the local field strength increases considerably. With the increasing cathode temperature, transition from field emission to thermal field emission occurs, causing an increase in current density and break down of vapour bubble. A dielectric with low boiling temperature and a low specific heat facilitates break down.